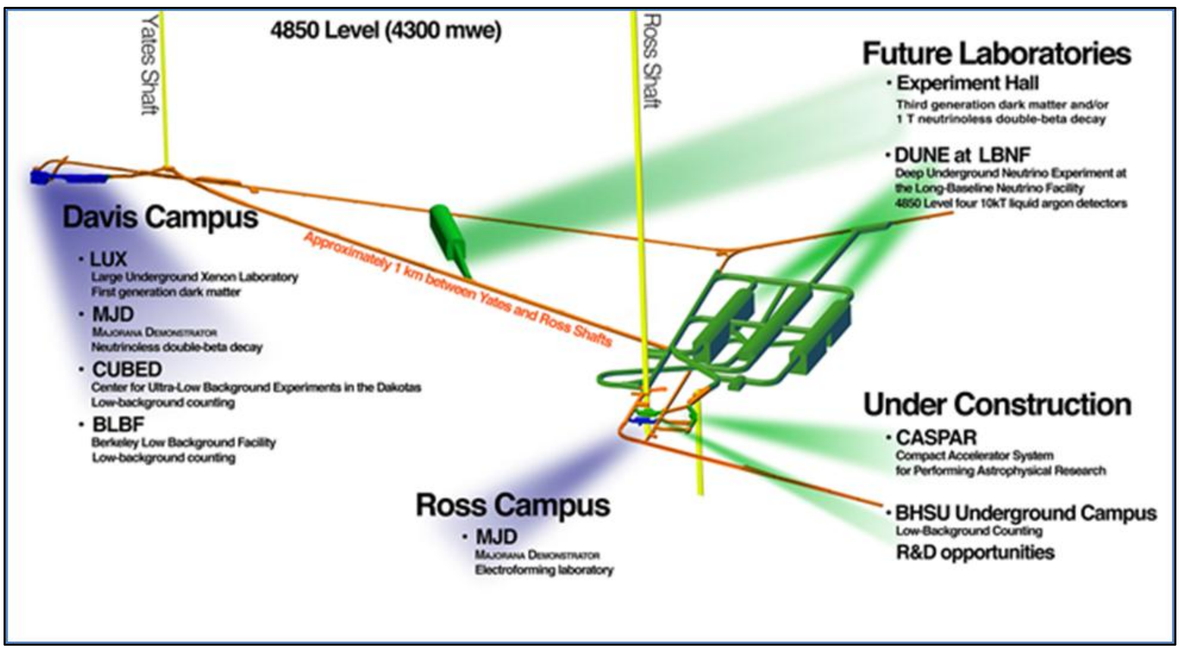
Annex 3C: Conventional Facilities at the Far Site

Long-Baseline Neutrino Facility (LBNF)/DUNE
Conceptual Design Report

May 2015



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ABBREVIATIONS AND ACRONYMS

Term	Expansion
2D, 3D	two dimensional, three dimensional
ACAMS	Asset Control and Alarm Monitoring System
ACBM	asbestos-containing building material
ACH	Air Changes (per hour)
ACI	American Concrete Institute
AGA	American Gas Association
AHU	Air Handling Unit
ANSI	American National Standards Institute
AoR	Area of Refuge
APTS	asset and personnel tracking system
ASME	American Society of Mechanical Engineers
ASPE	American Society of Plumbing Engineers
ASSE	American Society of Sanitary Engineering
ASTM	American Society for Testing and Material
AWWA	American Water Works Association
C	Celsius
CDR	Conceptual Design Report
CF	Conventional Facilities
CFM	cubic feet per minute
CR	communications room
dBA	decibel
DDC	Direct Digital Control
DocDB	LBNF's document database (LBNF-doc-####)
DOE	Department of Energy
DUNE	Deep Underground Neutrino Facility
DUSEL	Deep Underground Science and Engineering Laboratory
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
ES&H	Environment, Safety and Health
F	Fahrenheit
FEA	Finite Element Analysis
FEMA	Federal Emergency Management Agency
Fermilab	Fermi National Accelerator Laboratory
FLS	fire life safety
FMS	Facility Management System
ft	feet
GAC	Geotechnical Advisory Committee
GES	Geotechnical Engineering Services
gpm	gallons per minute
gsf	gross square feet
HMI	Human Machine Interface

Hp	Horse Power
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation and Air Conditioning
IBC	International Building Code
in	inch
IT	Information Technology
ksi	kilopascal
kt (or kton)	kiloton
kV	kilovolt
kVA	kilo volt amps (or kilowatt, electrical power)
kW	kilowatt
L	Level/Liter
LAr	Liquid Argon
LAr-FD	Liquid Argon far detector
LBNF	Long Baseline Neutrino Facility
LBP	lead-based paint
LCAB	Large Cavity Advisory Board
LFA	Lachel Felice & Associates
LHD	Load Haul Dump
m	meter
m^3	cubic meter
MBH	thousands of BTU's per hour
MDU	Montana-Dakota Utilities
MEP	mechanical/ electrical/ plumbing
MER	Mechanical Electrical Room
MK	McCarthy Kiewit Joint Venture
mm	millimeter
MPa	megapascal
MSHA	Mine Safety and Health Administration
MUTCD	Manual of Uniform Traffic Control Devices
NEC	National Electric Code
NEPA	National Environmental Policy Act
NESC	National Electric Safety Code
NFPA	National Fire Protection Association
NPDES	National Pollutant Discharge Elimination System
NSF	National Science Foundation
ODH	Oxygen Depletion Hazard
P5	Particle Physics Project Prioritization Panel
PCB	polychlorinated biphenyl
PDR	Preliminary Design Report (DUSEL)
PRV	pressure reducing valve assembly
psi	pounds per square inch
REED	(South Dakota) Research, Education and Economic Development (Network)
RFID	Radio Frequency Identification
RPBP	reduced pressure backflow preventer

SD SHPO	South Dakota State Historic Preservation Office
SDSTA	South Dakota Science and Technology Authority
sf	square feet
UPS	uninterruptible power supply
v	volt
VoIP	Voice over Internet Protocol
WBS	Work Breakdown Structure
WCD	water Cherenkov detector
WWTP	Waste Water Treatment Plant
yd^3	cubic yard

1 INTRODUCTION

1.1 Introduction to LBNF Conventional Facilities at the Far Site

The goal of the LBNF Project is to provide a facility to support the Deep Underground Neutrino Experiment (DUNE), which will explore physics beyond the Standard Model including the mass spectrum of the neutrinos and their properties aiming an intense proton beam created at the Fermilab Main Injector at neutrino detectors more than 1,300 kilometers away. The preferred physics location for DUNE far detector is the Sanford Underground Laboratory at Homestake (Sanford Laboratory) in Lead, South Dakota. This site was selected as part of a National Science Foundation effort to create a deep underground science and engineering laboratory. This process is discussed further in the LBNF Alternatives Analysis **[5]** where the scientific reasons for this location are detailed.

The Sanford Underground Laboratory is located at the site of the former Homestake Gold Mine, which is no longer an active mine. It is now being repurposed and modified to accommodate underground science. There are extensive underground workings that provide access to a depth of 8,100 ft, though there are no plans to dewater the facility beyond 6,000 ft below surface.

The reference conceptual design for the far detector is four 10-kT Liquid Argon (LAr) detectors contained with two caverns, each supporting two detectors. The mass of fluid quoted is the fiducial portion of the detector – the mass of vital importance for physics requirements. Excavated space for the detector will be larger than the fiducial. The caverns will be constructed at the 4850L of the facility near the Ross Shaft (see **Figure 1-1**).

The existing Sanford Underground Laboratory has many underground spaces, some of which can be utilized by LBNF. However, significant work is required to provide the space and infrastructure support needed for the experiment installation and operation. The scope of the underground facilities required for the LBNF includes new excavated spaces at the 4850L for the detector, utility spaces for experimental equipment, utility spaces for facility equipment, drifts for access, as well as construction-required spaces. Underground infrastructure provided by Conventional Facilities for the experiment includes power to experimental equipment, cooling systems, and cyberinfrastructure. Underground infrastructure for the facility includes domestic (potable) water, industrial water for process and fire suppression, fire detection and alarm, normal and standby power systems, sump pump drainage system for native and leak water around the detector, water drainage to the facility-wide pump discharge system, and cyber infrastructure for communications and security.

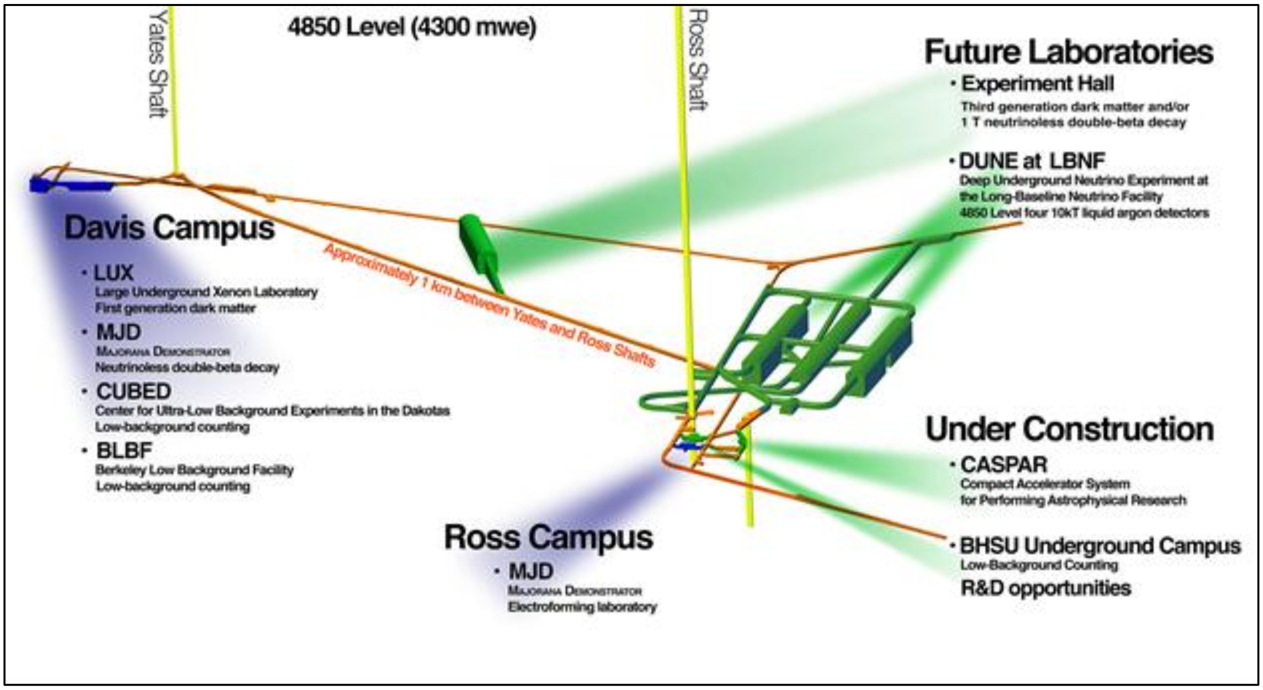

Figure 1-1 Location of LBNF at 4850L (Courtesy Sanford Laboratory)

In addition to providing new spaces and infrastructure underground, Conventional Facilities will enlarge and provide infrastructure in some existing spaces for use, such as the access drifts from the Ross Shaft to the new caverns.

The existing Sanford Laboratory has many surface buildings and utilities, some of which can be utilized for LBNF. The scope of the above ground work for Conventional Facilities includes only that work necessary for LBNF, and not for the general rehabilitation of buildings on the site, which remains the responsibility of the Sanford Laboratory. Electrical substations and distribution will be upgraded to increase power and provide standby capability for life safety. Additional surface scope includes a small control room in an existing building and a new building to support cryogen transfer from the surface to the underground near the existing Ross Shaft.

1.2 Participants

The far detector is planned to be located at the Sanford Laboratory site, which is managed by the South Dakota Science and Technology Authority (SDSTA). The design and construction of LBNF Far Site Conventional Facilities will be executed in conjunction with Sanford Laboratory staff.
The LBNF Project Conventional Facilities is managed by the Work Breakdown Structure (WBS) Conventional Facilities Project Manager for the Far Site and a deputy that has construction/construction management experience. The supporting team also includes a Far Site Deputy Project Manager who works directly with the Sanford Laboratory engineering staff. The Far Site Deputy Project Manager is also the LBNF Project liaison with the DUNE project to ensure the detector requirements are met and is responsible for all LBNF scope at the Far Site.

To date, Sanford Laboratory has utilized a team of in-house facility engineers to oversee multiple engineering design and construction consultants. Design consultants have specific areas of expertise in excavation, rock support, fire/life safety, electrical power distribution, cyberinfrastructure, cooling with chilled water, and heating/ventilation systems. The design consultant for LBNF's Conceptual Design is Arup, USA for both underground infrastructure and excavation. While these two scopes are provided for by the same company, two teams are provided based on their expertise. Interaction between Sanford Laboratory facility engineers, LBNF Far Site design teams, and the design consultants is done via weekly telephone conferences, periodic design interface workshops, electronic mail, and a purpose built Request for Information (RFI) system managed by LBNF. The Sanford Laboratory facility engineers coordinated all information between design consultants to assure that design efforts remain on track.

For the LBNF Conceptual Design phase, Hatch Mott MacDonald (HMM) is contracted to provide an independent review of the constructability of the project. HMM also provided an independent cost and schedule estimate, which was reconciled with the Arup costs and schedules to ensure the scope was adequately captured and costs were reasonable.

Construction at the Far Site will be executed under a Construction Manager/General Contractors (CM/GC) contract where the CM/GC will be, in industry terms, a CM at risk.

1.3 Codes and Standards

Conventional Facilities to be constructed at the Far Site shall be designed and constructed in conformance with the Sanford Underground Laboratory ESH Standards, (available publically through Sanford Laboratory's web site: http://sanfordlab.org/ehs/manual), and in conformance with the Fermilab ES&H Manual (FESHM) Chapter 1070, Work Smart Set, revision 8, dated December 2012 (http://esh.fnal.gov/xms/FESHM), but particularly the latest edition of the following codes and standards:

- Applicable Federal Code of Federal Regulations (CFR), Executive Orders, and DOE Requirements
- 2009 International Building Code (IBC) as enforced by the City of Lead, SD
- Sanford Underground Laboratory Subterranean Design Criteria, EHS-1000-L3-05
- "Fire Protection/Life Safety Assessment for the Conceptual Design of the Far Site of the Long Baseline Neutrino Experiment (LBNF)", a preliminary assessment dated October 11, 2011, by Aon/Schirmer Engineering
- The Occupational Health and Safety Act of 1970 (OSHA)
- Mine Safety and Health Administration (MSHA)
- NFPA 101, Life Safety Code
- NFPA 520, Standard on Subterranean Spaces, 2005 Edition
- NFPA 72, National Fire Alarm Code
- American Concrete Institute (ACI) 318
- American Institute of Steel Construction Manual, 14th Edition
- ASHRAE 90.1-2007, Energy Standard for Buildings
- ASHRAE 62, Indoor Air Quality
- 2009 National Electrical Code (NEC)
- American Society of Mechanical Engineers (ASME)
- American Society for Testing and Material (ASTM)
- American National Standards Institute (ANSI)
- National Institute of Standards & Technology (NIST)
- Insulated Cable Engineers Association (ICEA)
- Institute of Electrical and Electronics Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)

- American Society of Plumbing Engineers (ASPE)
- American Water Works Association (AWWA)
- American Society of Sanitary Engineering (ASSE)
- American Gas Association (AGA)
- National Sanitation Foundation (NSF)
- Federal American's with Disabilities Act (ADA) along with State of South Dakota ADA amendments.

Note: These requirements will only be applied to those facilities that are located at the ground surface and accessible to the public.

2 EXISTING SITE CONDITIONS

The SDSTA currently operates and maintains Sanford Underground Laboratory at Homestake in Lead, South Dakota. The Sanford Laboratory property comprises 186 acres on the surface and 7,700 acres underground. The Sanford Laboratory Surface Campus includes approximately 253,000 gross square feet (gsf) of existing structures. Using a combination of private funds through T. Denny Sanford, South Dakota Legislature-appropriated funding, and a federal Department of Housing and Urban Development (HUD) Grant, the SDSTA made significant progress in stabilizing and rehabilitating the Sanford Laboratory facility to provide for safe access and prepare the site for new laboratory construction. These efforts have included dewatering of the underground facility and mitigating and reducing risks independent of the former Deep Underground Science and Engineering Laboratory (DUSEL) efforts and funding.

The Sanford Laboratory site has been well-characterized through work performed by the DUSEL Project for the National Science Foundation (NSF). The following sections are excerpted from the DUSEL *Preliminary Design Report*, Section 5.1.1.4, *Facility Design*, and edited to include only information as it is relevant to the development of the LBNF Project. Other sections from the DUSEL *Preliminary Design Report* (PDR) [1], primarily Volume 5, *Facility Design*, are also used with permission in other sections of this LBNF CDR volume. The research supporting this work took place in whole or in part at the Sanford Underground Laboratory at Homestake in Lead, South Dakota. Funding for the DUSEL PDR and project development was provided by the National Science Foundation through Cooperative Agreements PHY-0717003 and PHY-0940801. The assistance of the Sanford Underground Laboratory at Homestake and its personnel in providing physical access and general logistical and technical support is acknowledged.

The following figures provide a context for the Sanford Laboratory site: **Figure 2-1** illustrates Sanford Laboratory's location within the region as a part of the northern Black Hills of South Dakota. **Figure 2-2** outlines the Sanford Laboratory site in relationship to the city of Lead, South Dakota, and points out various significant features of Lead including the surrounding property that still remains under the ownership of Barrick Gold Corporation[1]. Finally, **Figure 2-3** and **Figure 2-4** provide perspectives of the Sanford Laboratory Complex from a surface and aerial view of the property and its surroundings. These views illustrate the varied topography found throughout the site.

[1] Barrick Gold Corporation (Barrick) operated the former Homestake Gold Mine in Lead, SD and when they closed the mine operations, a portion of the land was donated to the state of South Dakota and the use of the property is governed by the Property Donation Agreement (PDA) between Barrick and the state of South Dakota. The state of South Dakota manages the development of the now Sanford Underground Laboratory site through the South Dakota Science and Technology Authority (SDSTA).

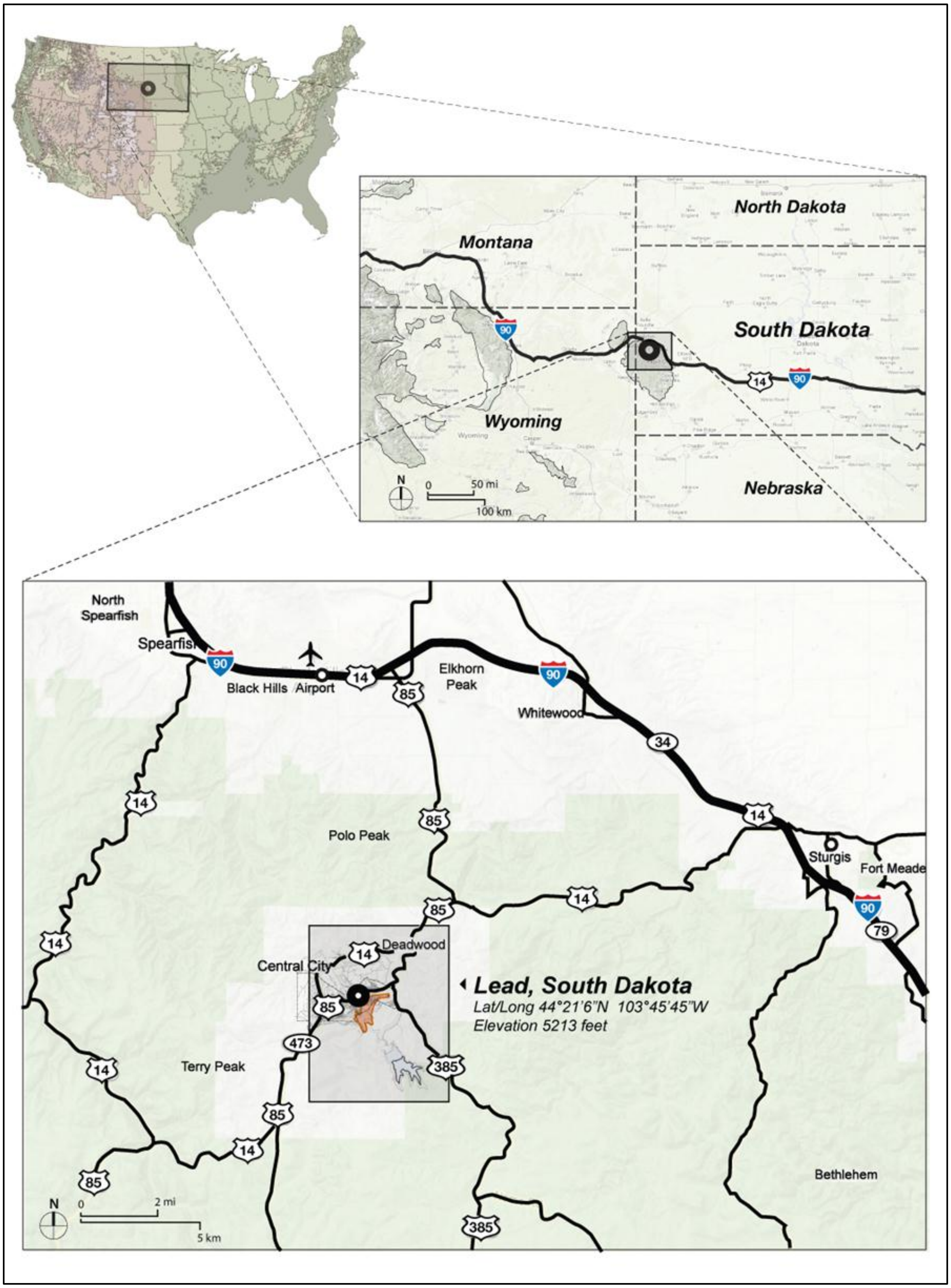

Figure 2-1: Regional Context showing the city of Lead, South Dakota. (Dangermond Keane Architecture, Courtesy Sanford Laboratory)

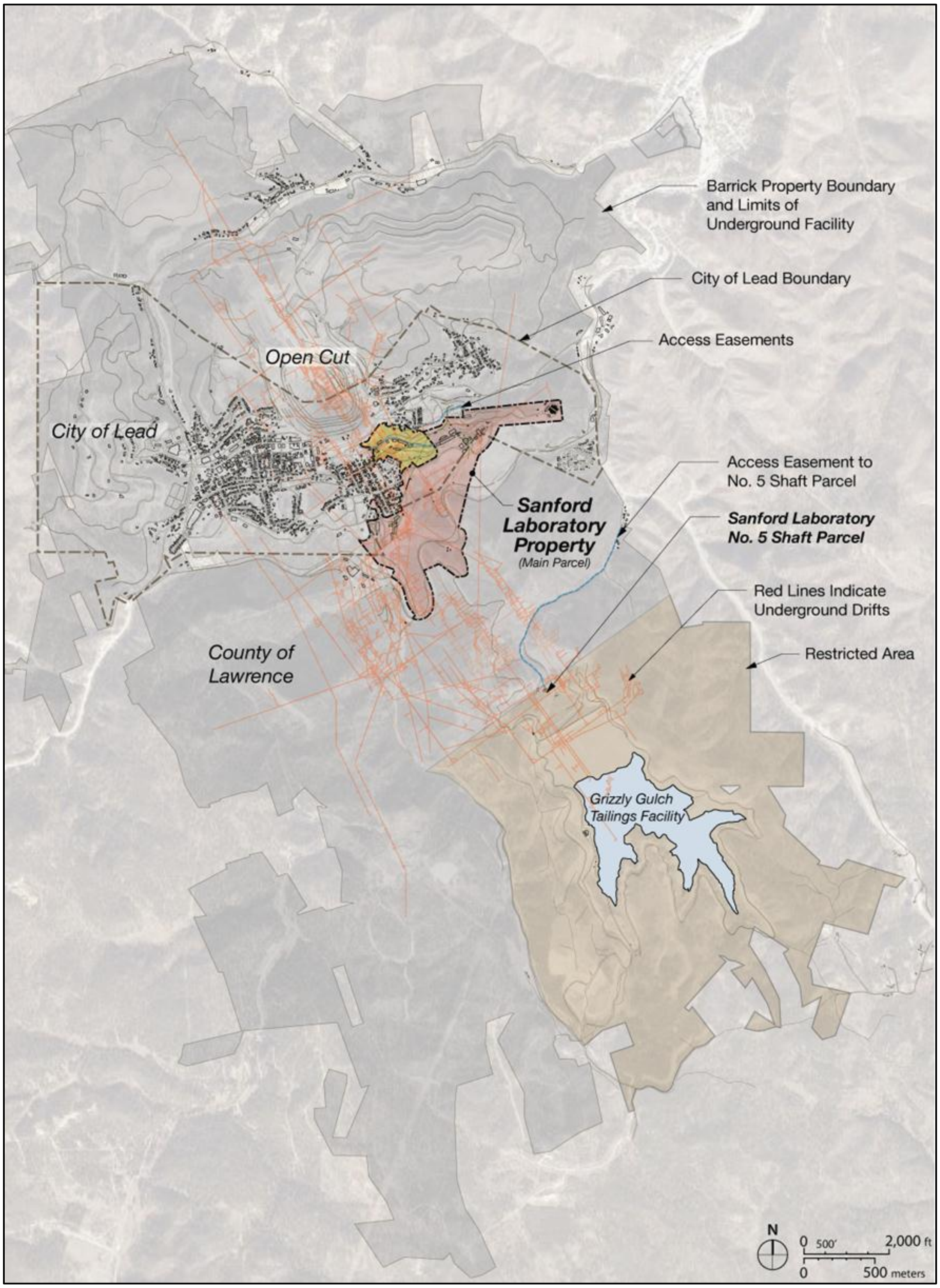

Figure 2-2: Sanford Laboratory Complex shown in the context of the city of Lead, South Dakota, and the property remaining under ownership of Barrick. Area shown in yellow is a potential future expansion of the SDSTA property. [Dangermond Keane Architecture, Courtesy of Sanford Laboratory]

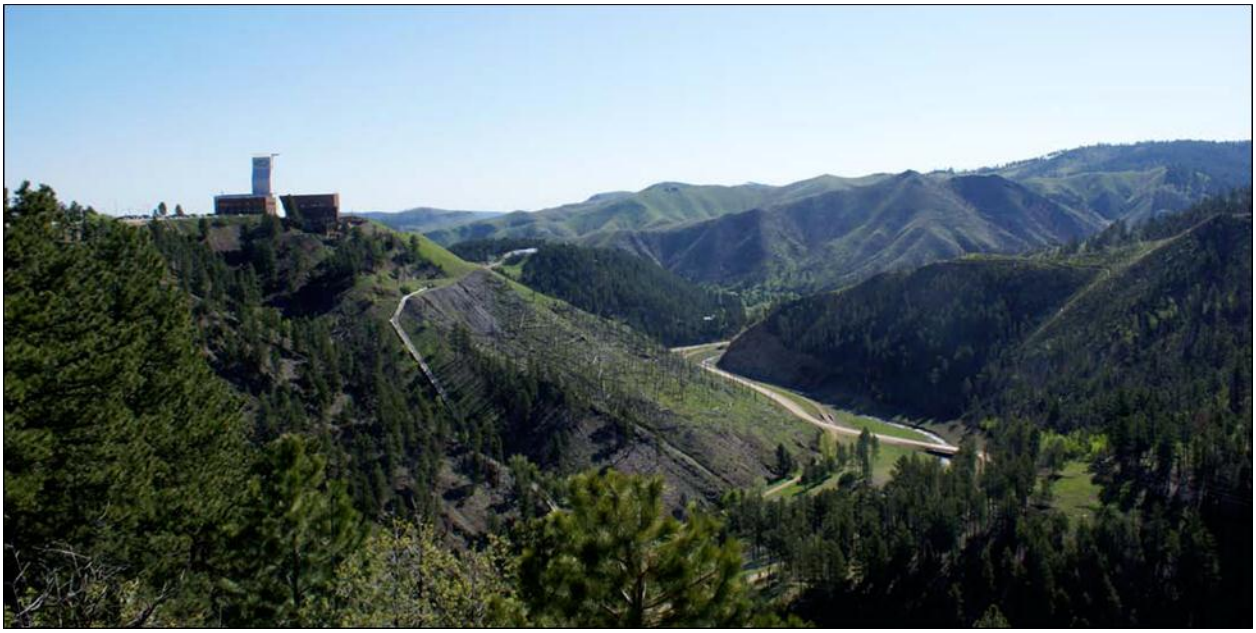

Figure 2-3: Top: Kirk Canyon Bottom: Sanford Laboratory Yates Campus (Courtesy of Sanford Laboratory)

Figure 2-4: Aerial view of Sanford Laboratory (boundary in red) and the adjacent city of Lead. (Dangermond Keane Architecture, Courtesy of Sanford Laboratory)

2.1 Existing Site Condition Evaluation

The existing facility conditions were assessed as part of the DUSEL Preliminary Design and documented in the DUSEL PDR, Section 5.2.4 [1], which is excerpted below. The portions of DUSEL's assessment that are included were edited to reflect current activities and to reference only that portion of the assessment that is pertinent to the LBNF Project. References to the DUSEL Project are from that time, and are now considered historic.

2.1.1 Existing Facilities and Site Assessment

Site and facility assessments were performed during DUSEL's Preliminary Design phase by HDR to evaluate the condition of existing facilities and structures on the Yates, and Ross Campuses. The assessments reviewed the condition of buildings proposed for continuing present use, new use, or potential demolition. Building assessments were performed in the categories of architectural, structural, mechanical/electrical/plumbing (MEP), civil, environmental, and historic. Site assessments looked at the categories that included civil, landscape, environmental, and historic. Facility-wide utilities such as electrical, steam distribution lines, water, and sewer systems were also assessed. The assessment evaluation was completed in three phases. The detailed reports are included in the appendices of the DUSEL PDR as noted and are titled:

- Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations (DUSEL PDR Appendix 5.E)
- Phase II Site and Surface Facility Assessment Project Report (DUSEL PDR Appendix 5.F)
- Phase II Roof Framing Assessment (DUSEL PDR Appendix 5.G)
- The site and facility assessments outlined above were performed during DUSEL's Preliminary Design as listed above and include a review of the following:
- Buildings proposed for reuse were evaluated for preliminary architectural and full structural, environmental, and historic assessments.
- Buildings proposed for demolition were evaluated for preliminary historic assessments.
- Preliminary MEP assessments were performed on the Ross Substation, #5 Shaft fan, Oro Hondo fan, Oro Hondo substation, and general site utilities for the Ross, Yates, and Ellison Campuses.
- The Waste Water Treatment Plant (WWTP) received preliminary architectural and structural assessments and a full MEP assessment.
- Preliminary civil assessments of the Kirk Portal site and Kirk to Ross access road were also completed.

2.1.1.1 Building Assessment Results

Results of the building assessment work, as detailed in the three reports referenced above, show that the buildings on the Ross and Yates Campuses were architecturally and structurally suitable for reuse or continued use with some upgrades or modifications.

2.1.1.2 Site Civil Assessment

Results of the civil assessment found in the Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations (DUSEL PDR Appendix 5.E) and Phase II Site and Facility Assessment, Project Report (DUSEL PDR Appendix 5.F) showed the following results:

- Water and sewer utilities on both the Ross and Yates Campuses need replacement.
- Roadway and parking lot surfaces need replacement and regrading.
- Drainage ways and steep slopes need maintenance.
- Retaining walls and transportation structures are in useable condition, with some maintenance, except for two failing retaining walls.
- Retaining walls and transportation structures need maintenance in the form of drainage improvements and minor repairs to section loss due to rust and erosion.
- Existing fencing and guardrails are a very inconsistent pattern of chain link, wood, and steel; much of the fencing is deteriorating or collapsed.
- Abandoned equipment/scrap-metal piles around the sites represent traffic and health hazards.
- Pedestrian and traffic separation is poorly defined.
- Existing traffic signs are faded and do not meet *Manual of Uniform Traffic Control Devices* (MUTCD) standards.

The Civil Site Assessment recommendations can be found in DUSEL PDR Appendix 5.E (Section 4, Page 4 (1) of the Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations); and DUSEL PDR Appendix 5.F (Section 2, Page (2.1) – 39 of the Phase II Site and Facility Assessment Project Report). All items that would cause immediate concern for the health and safety of on-site personnel have been addressed by the SDSTA by removing, repairing, or isolating the concerns. Other items are planned to be addressed by the SDSTA outside of the LBNF scope.

2.1.1.3 Landscape Assessment

The landscape assessment, found in DUSEL PDR Appendix 5.E (Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations), and DUSEL PDR Appendix 5.F (Phase II Site and Surface Facility Assessment Project Report) noted many of the same items as the site civil assessment: drainage issues, erosion concerns, abandoned equipment, and scrap metal. Soil conditions were noted as well as rock escarpments and soil stability concerns.

2.1.1.4 Site MEP Assessment

The site assessments, detailed in DUSEL PDR Appendix 5.E (Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations); and DUSEL PDR Appendix 5.F (Phase II Site and Surface Facility Assessment Project Report) found the electrical distribution condition to range from fair to excellent, depending on the age of the equipment. The Ross Campus recommendations generally consisted of upgrades to increase reliability. The Yates Campus recommendations call for a new substation to replace the old abandoned East Substation if significant loads are added to this campus.

The assessments also evaluated the natural gas and steam distribution systems. Natural gas is provided to the site at three locations and appears to have the capacity required to meet surface needs as they are currently understood. However, the natural gas supply is an interruptible supply (non-firm) and thus cannot be guaranteed. Either an upgrade to Montana-Dakota Utilities (MDU, local natural gas supplier) supply lines (outside the scope of this Project) or an alternate fuel/heating source would be needed to meet the surface needs if uninterruptable supply is required in future design. The steam boiler systems have been dismantled and should not be reused. The existing components represent placeholders for routing for new distribution if steam is re-employed.

The site telecommunications service currently is provided by Midcontinent Communications, Rapid City, South Dakota, and a fiber-optic data connection is from the South Dakota Research, Education and Economic Development (REED) Network (see DUSEL PDR Chapter 5.5, Cyberinfrastructure Systems Design, for details on these service providers) [1]**.** Both services are quite new and have historically been very reliable. The site distribution system is a mix of copper and fiber, copper being quite old and fiber very new. The Ross and Yates Campus' recommendations are to increase reliability as the campuses are developed.

2.1.1.5 Environmental Assessment

The environmental assessment, found in DUSEL PDR Appendix 5.F (*Phase II Site and Surface Facility Assessment Project Report)* looked for contamination from lead-based paint (LBP); polychlorinated biphenyls (PCBs) contained in electrical equipment, lubrication oils, and hydraulics; asbestos-containing building materials (ACBMs); heavy metals; the historic presence of petroleum hydrocarbons and chlorinated solvents; molds; historic uncontrolled discharges of domestic sewage; industrial wastewater; and storm-water runoff. Environmental results showed some LBPs in various locations across both the Ross and Yates Campuses. No PCB concentrations above Environmental Protection Agency (EPA) regulatory standards were encountered, and no heavy metals above EPA regulatory standards were found.

2.1.1.6 Historic Assessment

The former Homestake Gold Mine site is a major component of the Lead Historic District. Most of the DUSEL (now Sanford) Complex is within the historic district; thus, work on the DUSEL site must conform to the National Historic Preservation Act of 1966, as amended. These standards recognize that historic buildings and sites must change with time if they are to meet contemporary needs but that alterations to meet these needs can be done in a manner that is sensitive to the historic property. **Figure 2-5** is a historic photograph showing the former Homestake Mining Company milling operation and components of the Yates Campus. **Figure 2-6** shows the boundaries of the Lead historic district.

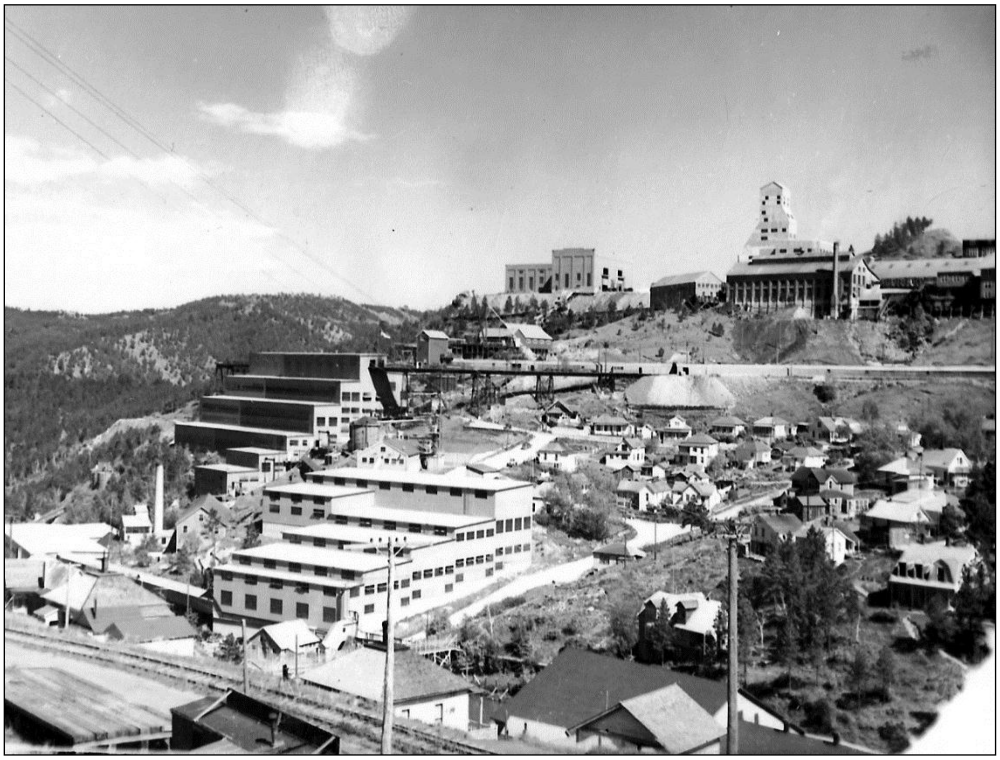

Figure 2-5: Historic Photo of Milling Operation, Yates Headframe, Hoist, and Foundry (Courtesy Homestake Adams Research and Cultural Center)

The historic assessment consisted of the full assessment of ten transcendent and eight support buildings. Transcendent buildings have the most significant historic value and represent an operation that was unique or limited to the site. Support buildings represented a function or activity that, although performed on the site, could have been done off site. Of the ten transcendent buildings, nine were deemed to have significant historic value while one held only moderate historic value. Seven of the support buildings held moderate historic value, while the eighth has only limited historic value. Sixteen other buildings received a preliminary historic assessment. Two were deemed to have significant historic value, 13 held moderate historic value, and the last was deemed to be of limited historic value.

To assist the DUSEL Project in understanding the historic requirements for the Project, a meeting was held with the South Dakota State Historic Preservation Office (SD SHPO) in June 2010. The DUSEL team provided a Project overview for the SD SHPO staff and took a site tour so the SHPO staff could develop an understanding of the Project. The SD SHPO staff members were pleased, for the most part, with the direction the design team was taking for the Project. SD SHPO provided recommendations to DUSEL for documentation and preservation options that will need to be addressed during Final Design to meet mitigation requirements for any facilities that may ultimately be removed. LBNF is not currently planning to remove any existing structures.

Note: The historic assessment prepared for this portion of the overall site assessment is not the formal historic assessment that is in process to comply with the National Environmental Policy Act (NEPA) strategy.

The entire historic assessment process and results can be viewed in DUSEL PDR Appendix 5.E (Phase I Report, Site Assessment for Surface Facilities and Campus Infrastructure to Support Laboratory Construction and Operations), and DUSEL PDR Appendix 5.F (Phase II Site and Surface Facility Assessment Project Report).

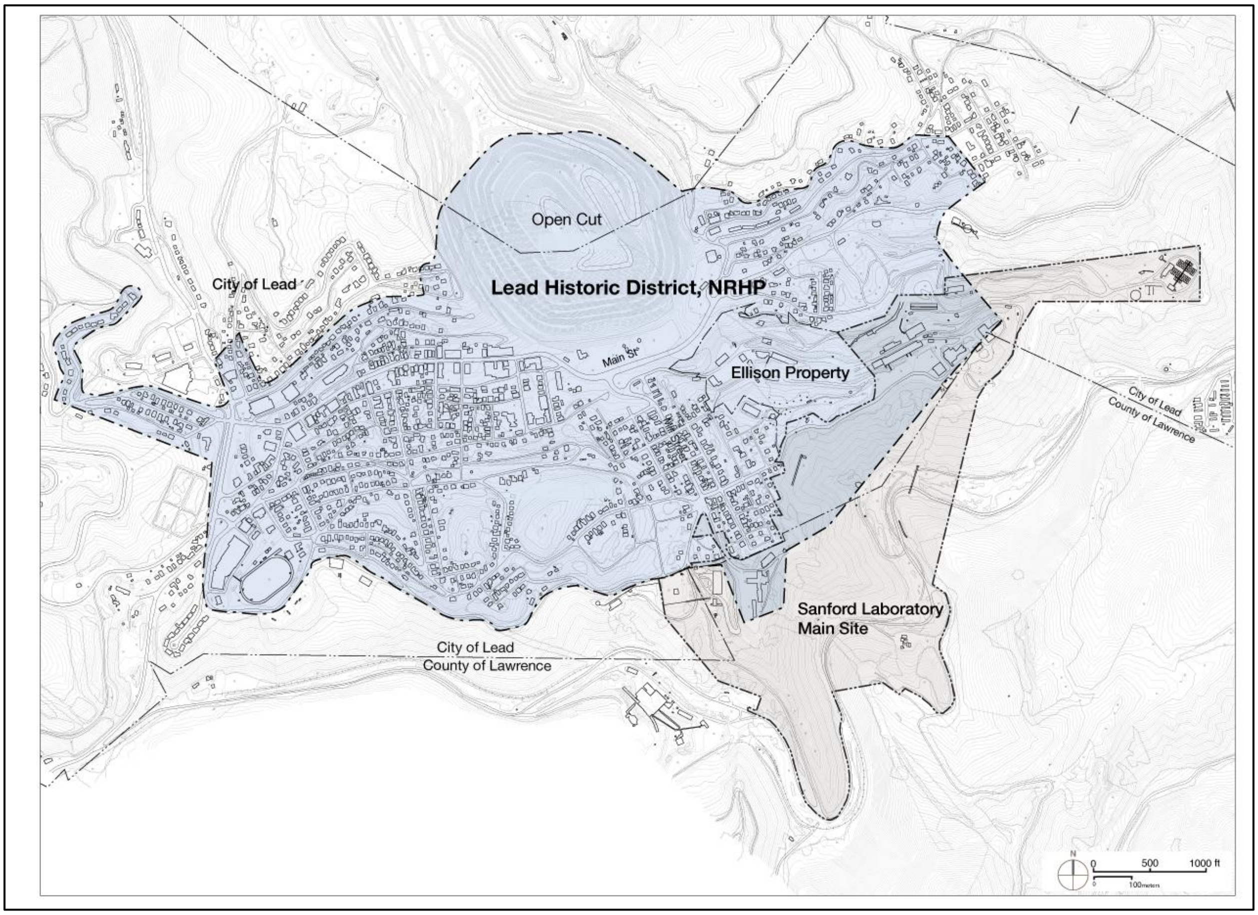

Figure 2-6: Map of Lead Historic District. (Dangermond Keane Architecture, Courtesy of Sanford Laboratory)

2.2 Evaluation of Geology and Existing Excavations

LBNF Far Site facilities are planned to be constructed at Sanford Laboratory, which is being developed within the footprint of the former Homestake Gold Mine, located in Lead, South Dakota. The accessible underground mine workings are extensive. Over the life of the former gold mine over 360 miles of drifts (tunnels) were mined and shafts and winzes sunk to gain access to depths in excess of 8,000 feet. A number of underground workings are being refurbished by Sanford Laboratory and new experiments are being developed at the 4850L, the same level as proposed for LBNF facilities. Geotechnical investigations and initial geotechnical analyses were completed for the DUSEL Preliminary Design and are described in detail in the DUSEL PDR. Additional geotechnical investigation and analysis was performed in 2014 specific to the LBNF project. Below are summaries of these two efforts, including work completed for DUSEL that is applicable to LBNF as excerpted from the DUSEL *Preliminary Design*

Report, *Section 5.3*. Much of the work completed for the alternate detector technology considered during DUSEL [water Cherenkov detector (WCD)] is also applicable to the current design at the 4850L.

2.2.1 Geologic Setting

The Sanford Laboratory is sited within a metamorphic complex containing the Poorman, Homestake, Ellison and Northwestern Formations (oldest to youngest), which are sedimentary and volcanic in origin. An amphibolite unit (Yates Member) is present within the lower known portions of the Poorman Formation. While the Yates Member is the preferred host rock for the LBNF excavations at 4850L, the LBNF cavity has been located in the Poorman formation to isolate it from the remainder of the level. The layout adopted on the 4850L attempts to optimize the needs for ventilation isolation, access control, and orientation relative to the beam line.

2.2.2 Rock Mass Characterization - DUSEL

One of the goals of the geotechnical investigations performed by the DUSEL Project was to provide information for the excavation and stabilization of a large cavity for a Water Cherenkov Detector (WCD) supporting the Long Baseline Neutrino Experiment (LBNE). Characterization of the rock mass (see DUSEL PDR Sections 5.3.2 and 5.3.3) was accomplished through a program of mapping existing drifts and rooms in the vicinity of planned excavations, drilling and geotechnical logging of rock core samples, and laboratory measurements of the properties of those samples. Much of the geotechnical work performed for WCD is applicable to LBNF at the 4850L.

As part of the Preliminary Design process, the DUSEL Project engaged two advisory boards to provide expert review of the geotechnical investigation and excavation design efforts. The Geotechnical Advisory Committee (GAC) was an internal committee that focused primarily on geotechnical investigation and analysis. The Large Cavity Advisory Board (LCAB) was an internal high-level board that focused on geotechnical investigations and excavation design of the WCD cavity in support of the LBNE Project, much of which is applicable to LBNF at the 4850L. The Geotechnical Engineering Services (GES) contract, which was used to execute geotechnical investigations, was reviewed by the GAC and the LCAB and included the following scope of work:

- The mapping program included drift mapping at the 300L and 4850L and 4,400 ft (1,340 m) of existing drifts mapped in detail and 2,600 ft (793 m) of newly excavated drifts and large openings mapped in detail (Davis Campus, Transition Area, and associated connecting drifts).
- The drilling program included the completion of nine new holes totaling 5,399 ft (1,646 m) of HQ (4-inch) diamond core drilling, which incorporated continuous logging, continuous core orientation, detailed geotechnical and geological logging, full depth continuous televiewer imaging, and initial groundwater monitoring.
- The in situ stress measurement program included stress measurements in three locations; two sites in amphibolite and one site in rhyolite for the total of eight measurements (six in amphibolite and two in rhyolite).
- The laboratory testing program included uniaxial compressive strength tests (80 samples that incorporated elastic constants and failure criteria), indirect tensile strength tests (40 samples),

triaxial compressive strength tests (63 samples), and direct shear strength of discontinuities (36 samples).

Geotechnical investigations were initiated by DUSEL in January 2009 and executed by RESPEC Inc., with Golder Associates and Lachel Felice & Associates (LFA) as their main subcontractors. The initial scope was modified to include the addition of a 100kT water Cherenkov detector (WCD). The scope was further modified, resulting in the requirement for the potential to include up to two 100kT WCDs into the DUSEL Preliminary Design effort. In mid-2010, the DUSEL Preliminary Design scope was narrowed to one WCD. Subsequently, the project has considered locating a LAr detector on the same level.

In mid-2009, an initial geotechnical program was executed by DUSEL, first on the 300L, then on the 4850L of the Homestake site. This program included site mapping, reconnaissance level geotechnical drilling and core logging, in situ stress measurements, optical and acoustic televiewer logging, numerical modeling, laboratory testing, initial surveying, and generation of a three dimensional (3D) Geological and Geotechnical Model. Additional tasks added in 2010 included characterization of ground vibrations from blasting associated with the Davis Campus excavation activities, and groundwater monitoring. A *Geotechnical Engineering Summary Report* (DUSEL PDR Appendix 5.H) was completed in March 2010, which recommended additional drilling and mapping to address data gaps and reduce uncertainty in the characterization of the rock mass that would be important for future phases of design. All of the geologic, geotechnical, and hydrogeologic information collected has been used to advance the Conceptual Design of the LBNF at the 4850L.

The geotechnical site investigations area on the 4850L, showing boreholes, in situ measurement stations, and planned cavities within the triangle of drifts between the Ross and Yates Shafts, is presented in **Figure 2-7**.
Note: Only one core (hole J) was collected in the Poorman formation for DUSEL, as this was not the intended rock formation to be used at the time of the investigation.

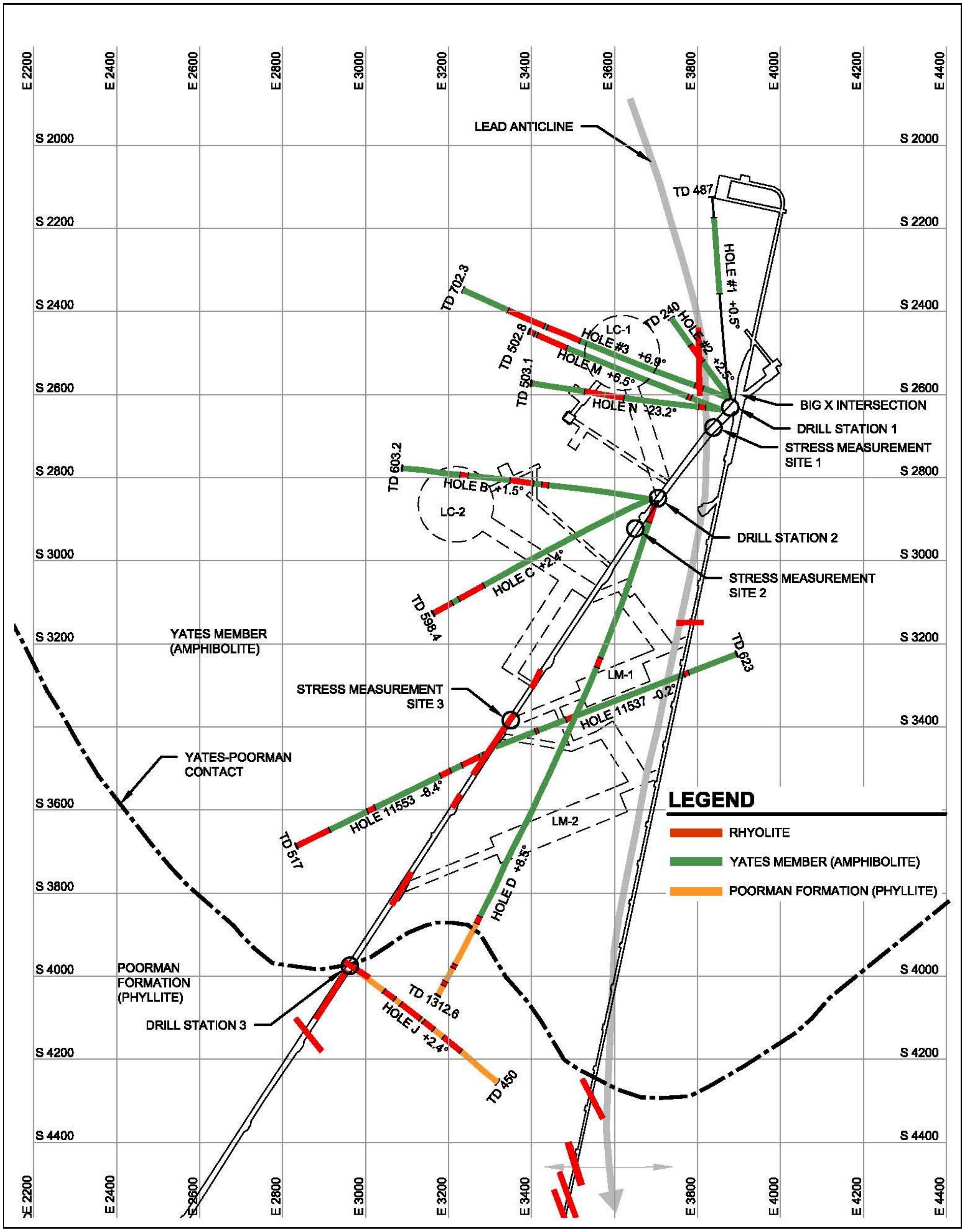

Figure 2-7: General Geologic Map at the 4850L and Location of Drill Holes (Golder Associates, Courtesy Sanford Laboratory)

Since their formation, the host rock units have been subject to periods of significant structural deformation. Deformations during the Precambrian era lead to the development of complex fold patterns, and local shear zones. Brittle deformations that took place during the Tertiary era resulted in the development of joint sets, veining, faulting and the intrusion of dikes [2]. Tertiary rhyolite dikes cross-cut the Precambrian rock units across the former mine site, from surface (open cut) to the deepest development levels (>8,000ft). In the areas of the 4850L observed and investigated to date, these dikes are commonplace. Rhyolite is estimated to constitute some 40% of the country rock volume in the area of the proposed campus. Faulting and veining have also been observed within the host rock mass [*Lachel Felice & Associates, Geotechnical Engineering Services Final Report for 4850L **Mapping*** [3], and Golder Associates, *LBNF Far Site Detector Excavation Conceptual Design: 4850 Level Liquid Argon (LAr) Reference Design Final Report* [4]**].**

The in situ stress levels at various levels of the Sanford Laboratory underground facility have been measured on a number of occasions. The major principle stress, at depth, is sub-vertical. Recent measurements on the 4850L report a range of vertical stress values, from 22 to 61 MPa (3.2 to 8.8 ksi) (average 44Mpa/6.4ksi). Measured intermediate: major and minor: major stress ratios were reported to be 0.6 to 0.8 and 0.5 to 0.7 respectively. For further details, see Golder's Geotechnical Engineering Services, *In Situ Stress Measurement Deep Underground Science and Engineering Laboratory* [5]**.**

The intact hard metamorphic rocks are generally of low primary hydrologic conductivity. During historic mine operations, most water inflows were observed to be local and typically attributed to secondary permeability [6]. A recent evaluation by Golder [4] estimates the typical inflow rate of about 1 to 2 gallons per minute per mile of underground workings. Some additional flow may be anticipated in the upper workings where fractures may be generally more weathered, open and directly connected to the surface and/or the Open Cut.

2.2.3 Rock Mass Characterization – LBNF

Following a similar strategy as DUSEL, the LBNF project initiated a second geotechnical program in 2013 to evaluate the specific location under consideration and evaluate its appropriateness for the proposed design. This was undertaken in two phases. The first phase was a mapping of the existing spaces surrounding the proposed rock mass using both visual techniques and laser scanning to understand the rock mass and inform the scope of the second phase. The second phase included drilling of four HQ (2.5" diameter) core holes ranging in length from 477 to 801 feet as well as two 6" diameter core holes ~30' each. The smaller diameter cores were then evaluated for the following characteristics:

- Core recovery percent
- Rock Quality Designation (RQD) percent
- Rock type, including color, texture, degree of weathering, and strength
- Mineralogy and presence of magnetic sulfides
- Character of discontinuities, joint spacing, orientation, aperture,
- Roughness, alteration, and infill (if applicable)

Representative samples were selected from the overall core to test material strength and chemical characteristics. The geotechnical site investigations area on the 4850L, showing boreholes is shown in **Figure 2-8**.

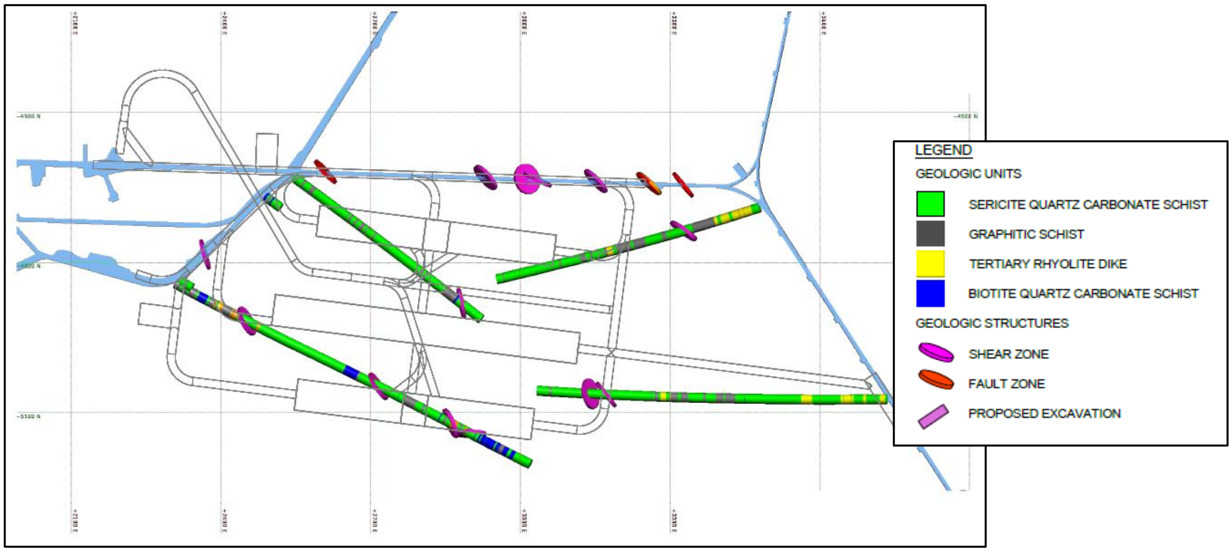

Figure 2-8: LBNF Core Locations and Geological Features

The holes from which the smaller diameter core was removed were studied in several ways. An absolute survey was conducted to allow the core holes to be plotted relative to cavern designs. An optical televiewer was passed through each small hole to visualize the rock mass. This technique allows visualization of foliation, joint openings, healed joints, and geological contact between rock types. An acoustical imaging device was also used in one hole to complement the optical information. The permeability of the rock was tested by pressurizing the small holes at various intervals to determine if joints allowed for the flow of water outside of the holes (hydraulic conductivity). In all cases, the hydraulic conductivity was well below what can be accomplished using manmade techniques such as grouting. Two of the small holes were plugged and instrumented to determine if water would flow into the holes over time. This test found very low flow rates (.0013-.0087 gpm). Ongoing evaluation of pressure build in these holes was inconclusive, as blast induce fracturing near the existing drifts allow the holes to depressurize outside of the test instruments.

The larger (6”) diameter cores and holes were used for strength and stress testing. In-Situ stress was tested by drilling a smaller diameter hole first, then gluing a strain gage at 30-36 feet within the depth. As the larger diameter core was removed, this strain gage recorded the relaxation of the rock. The removed core was re-drilled to provide smaller diameter samples at specific orientations for strength testing, as the strength of the material varies based on applied force direction relative to the foliation of the rock. These samples were also tested for time dependent movement.

LBNF followed a review approach for the analysis performed by Arup by enlisting industry leaders as part of a Neutrino Cavity Advisory Board (NCAB). This board reviewed the philosophy and results of the geotechnical investigation program as well as the preliminary excavation design. Their conclusions indicated that no additional drilling would be required to provide design information for the project and the overall design approach was appropriate. They provided many recommendations that will benefit the advancement of design.

For further details, see Arup's Geotechnical Interpretive Report, A/E Services for Site Investigation in Support of the LBNF Far Site Conventional Facilities Project [5]

2.2.4 Geologic Conclusions

The recovery of rock cores, plus geologic mapping, were performed to determine if discontinuities in the rock mass exist that would cause difficulties in the construction and maintenance of planned excavations. In general, the proposed locations of the excavations do not appear to be complicated by geologic structures that cause undue difficulties for construction. This information, along with measurement of in situ stresses, allowed initial numerical modeling of the stresses associated with the anticipated excavations. A sample of some of the modelling done is provided in **Figure 2-9** 2D and 3D numerical modeling was then used to design ground support systems that will ensure that the LBNF caverns, in particular, remains stable. The excavation design, which is influenced by anticipated methods of excavation and sequence of excavation, is described in the Arup 30% Preliminary Design [4]**,** followed by the means by which the excavations will be monitored to ensure their long-term stability.

The overall analysis of the work indicates that:

- the rock in the proposed location of the LBNF caverns is of good quality for the purposes of the LBNF Project
- preliminary numerical modeling shows that a large cavern of the size envisioned can be constructed
- a workable excavation design has been developed.

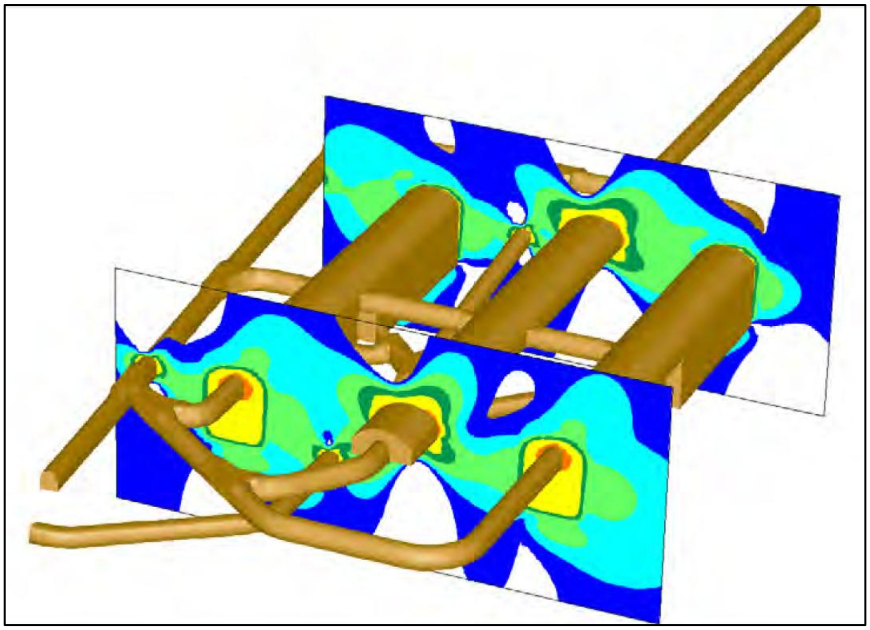

Figure 2-9: Contour of Stress Safety Factor Indicating Influences Between Caverns

2.3 Project-Wide Considerations

There are several project-wide considerations, many with environmental considerations that must also be considered. These are discussed below.

2.3.1 Environmental Protection

The LBNF Project will prepare designs and execute construction and operations of the LBNF at the Far Site in accordance with all codes and standards to ensure adequate protection of the environment. The Sanford Laboratory codes and standards outline the requirements for work at the site.

The overall environmental impact of the LBNF Project will be evaluated and reviewed for conformance to applicable portions of the National Environmental Policy Act (NEPA).

A programmatic agreement (PA) is being discussed with the SHPO for managing historic properties associated with the Sanford Lab as part of the NEPA process.

Several specific environmental concerns will be addressed during the project. These are described in the subsections below.

2.3.1.1 Environmental Controls during Waste Rock Disposal

There are a number of components to the waste rock handling system, most of which are either underground or on SDSTA property. The most visible component of the system to the public is a steep angle surface conveyor which conveys excavated material from the Ross Shaft overland to the Kirk Road ~500’ vertical feet downhill and is discussed further in Section **4.7**. From this point, trucks will transport the material via public roads to an abandoned open cut several miles south of the facility.

Several controls are included in the waste rock handling system design to protect both the equipment and the community. The existing belt magnet provides a first defense against belt damage due to rock bolts, loader bucket teeth, etc. Standard safety controls, including pull cords, drift switches, zero-speed switches, and guarding provide further protection for both the equipment and operators. A combination of dust collection and suppression will ensure that all environmental standards are met or exceeded. The Facility Management System (FMS) will create interlocks to limit the potential for human error. All conveying equipment is located on SURF property, which has security measures in place to prevent access from the public.

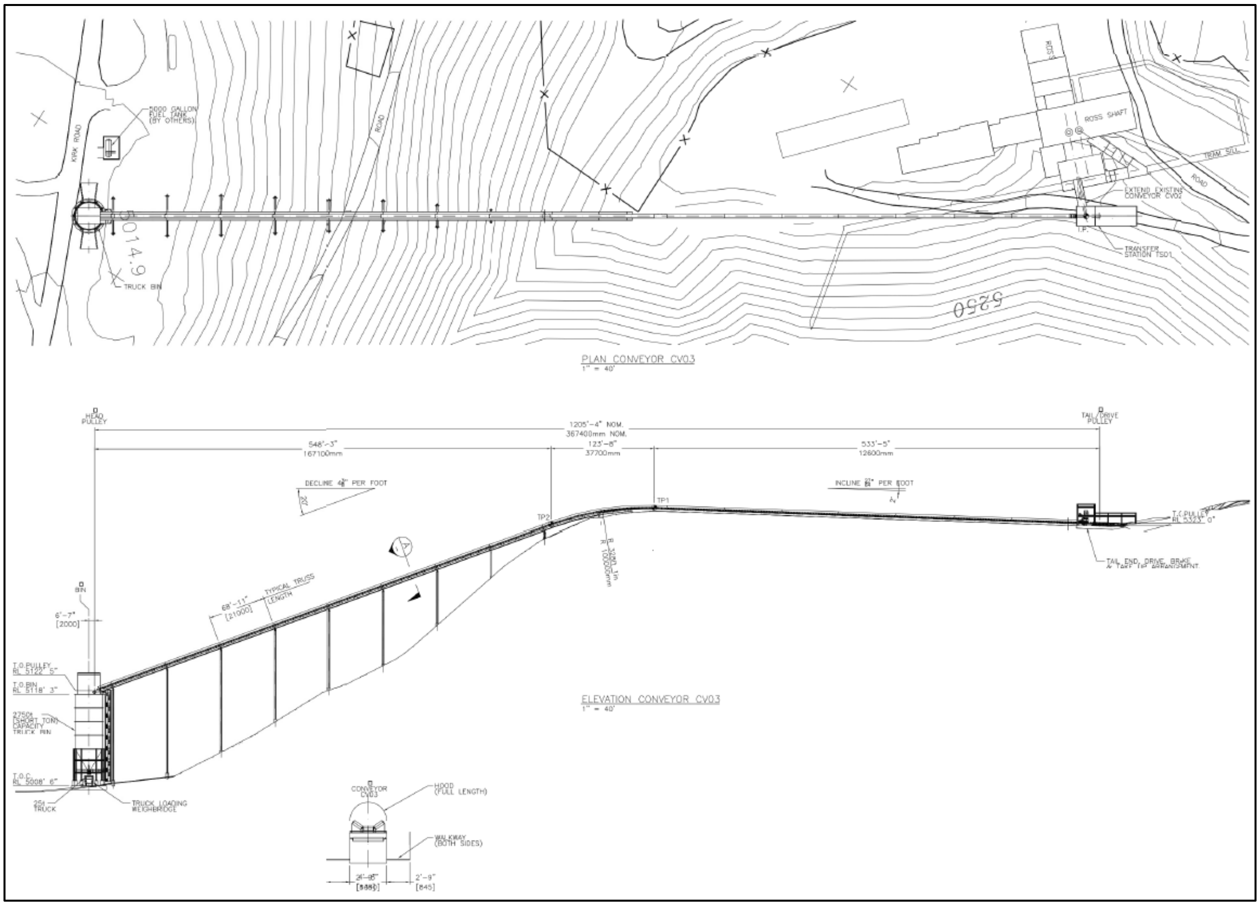

Figure 2-10: Schematic of Steep Angle Conveyor for Waste Rock Handling. (SRK, Courtesy Sanford Laboratory)

2.3.1.2 Waste Water Disposal Underground

To ensure environmental contaminants are not introduced into the lab-wide dewatering system, experimental space sumps will be able to be tested prior to discharge into the main drainage system. If contaminants are found, the experiment will be required to treat the water, or the water will be manually removed via tanks for proper disposal at the expense of the collaboration. A similar control will be provided within the cryogenic compressor building at the surface, providing a buffer volume to avoid contamination to sewer from building drains.

2.3.2 Safeguards and Security

The Sanford Underground Research Factility has worked directly with the Department of Homeland Security to develop appropriate security measures for the Far Site. These systems include measures such as site fencing and secured gates, electronic locks for buildings, personell monitoring of all open accesses to the underground as well as others. LBNF will comply with these safeguards.

2.3.3 Emergency Shelter Provisions

Guidelines established by the Federal Emergency Management Agency (FEMA) in publications TR-83A and TR-83B and referenced in Section 0111-2.5, DOE 6430.1A may, if determined to be applicable, be used to assess the design of the buildings to insure safe areas within the buildings for the protection of the occupants. These protected areas would also serve as dual-purpose spaces with regard to protection during a national emergency in accordance with the direction given in Section 0110-10, DOE 6430.1A.

FEMA guidelines indicate that protected areas are as follows:

- on the lowest floor of a surface building
- in an interior space, avoiding spaces with glass partitions
- areas with short spans of the floor or roof structure are best; small rooms are usually safe, large rooms are to be avoided.

2.3.4 Energy Conservation

Early 2012, in a position paper titled "Fermilab Strategy for Sustainability," the likelihood of attaining the LEED Gold certification for LBNF facilities was discussed. The context for that analysis was the requirement by DOE that all new buildings and major building modification over $5M must obtain LEED Gold certification from the U.S. Green Building Council (USGBC). That paper was written in part to support a Fermilab request to DOE for an exemption from the LEED Gold requirement for LBNF. The LEED Gold requirement was first articulated in a memo by then-Secretary Samuel Bodman on February 29, 2008, and was subsequently incorporated into DOE's Strategic Sustainability Performance Plans (SSPPs) for 2011 and 2012.

In April, 2012, it was determined by DOE that the "Bodman memo" had, in fact, been rescinded, and DOE removed the LEED Gold requirement for new projects. The 2013 SSPP does not include any LEED requirements, but relies on all new construction meeting the federal Guiding Principles (GP) for High Performance and Sustainable Buildings. The GP were first officially articulated in the 2006 Federal Leadership in High Performance and Sustainable Buildings interdepartmental MOU, which was signed by 20 federal departments. The five GP are as follows:

- Employ Integrated Assessment, Operation, and Management Principles
- Optimize Energy Performance
- Protect and Conserve Water
- Enhance Indoor Environmental Quality
- Reduce Environmental Impact of Materials

These GP were included explicitly in Executive Orders 13423 and 13514, then in DOE Order 430.2B and its replacement, DOE Order 436.1. Each of the five GP has a set of specifically required goals intended to implement it. There are 34 such specific and mandatory goals. The GP can be found in detail at http://www.wbdg.org/references/fhpsb_new.php. Compliance with the GP appears to be the main formal requirement for demonstrating sustainability in new construction projects. Sustainability is also a prominent goal in DOE Order 413.3B, however, the means of achieving the goal is less prescriptive and formal in DOE Order 413.3B than what is required by the Guiding Principles. DOE Order 413.3B requires only that a Sustainability Plan appropriate to the project be developed and implemented. It does not dictate means and/or methods.

Efforts to apply the GP and develop a Sustainability Plan for the project should complement each other. Both processes will be informed by widely available resources. In making the argument that LEED certification for LBNF is unrealistic, we have committed to the use of LEED concepts and principles to inform decisions about sustainable design, but to avoid confusion, it may be preferable to avoid the term “LEED” altogether and say that we will use USGBC as a resource. There are numerous other resources for sustainable design available to Fermilab, including for example, “Laboratories for the 21st Century” or Labs21, which was developed by DOE and USEPA. It has the virtue of being aimed specifically at buildings that use higher than average amounts of energy. Unlike LEED and USGBC, Labs21 is not in the business of certification. It is mostly a clearinghouse for all sorts of technical guides relating to designing more efficient buildings. Several DOE sites already rely on Labs21 for performance benchmarking.

The LBNF Project has already begun evaluating LBNF facilities using the Guiding Principles criteria, and credit has provisionally been taken for 11 of the 34 total required items, based on the near site. The requirements in the Guiding Principles (GP) are more policy/process oriented, whereas the LEED credits are more building/site oriented. For the near site, it is believed that LBNF can eventually meet almost 50% of the GP requirements simply by citing Fermilab-level policies, or overall Lab performance. Of the remaining individual requirements of the Guiding Principles, almost all of them are easily incorporated into the design of the project. Examples are the use of water conserving fixtures, energy efficient lighting, metering, and using materials with recycled and/or bio-based content.

The most difficult of the individual requirements to comply with is to reduce the energy use by 30% relative to the baseline building performance prescribed by the ASHRAE 90.1-2007 standard. This goal originates in the Energy Policy Act (EPAct) of 2005 and the Energy Independence and Security Act (EISA) of 2007. This goal becomes particularly difficult for the types of facilities, i.e. unconventional, high energy using, that Fermilab typically builds.

LBNF confirms the commitment to meet as many of the GP requirements as is reasonably feasible, recognizing that compliance in many of the planned facilities LBNF is designing may not be straightforward. In these cases LBNF will take every opportunity to inform our design decisions by taking advantage of resources such as the USGBC, and Labs21.

2.3.5 DOE Space Allocation

The elimination of excess facility capacity is an ongoing effort at all DOE programs. Eliminating excess facilities (buildings) to offset new building construction (on a building square foot basis) frees up future budget resources for maintaining and recapitalizing DOE’s remaining facilities.

DOE has determined that the provisions for elimination of excess space apply to the DOE leased space at SURF. The LBNF Far Site Project requires 147,000 gross square feet of space offset which was obtained as part of the overall DOE Space Allocation Space Bank Waiver for LBNF, which assigns elimination of excess facilities capacity elsewhere in DOE labs to offset new LBNF square footage. See [7].

2.4 Surface Facility

2.4.1 Existing Surface Facility

The Sanford Laboratory property of 186 acres consists of steep terrain and man-made cuts dating from its mining history. There are approximately 50 buildings and associated site infrastructure in various states of repair. A select few of these buildings at the Ross Complex and the main utilities are needed by the LBNF experiment and will be upgraded and rehabilitated as necessary. A layout of the overall Sanford Laboratory architectural site plan for SURF is found in **Figure 2-11**.

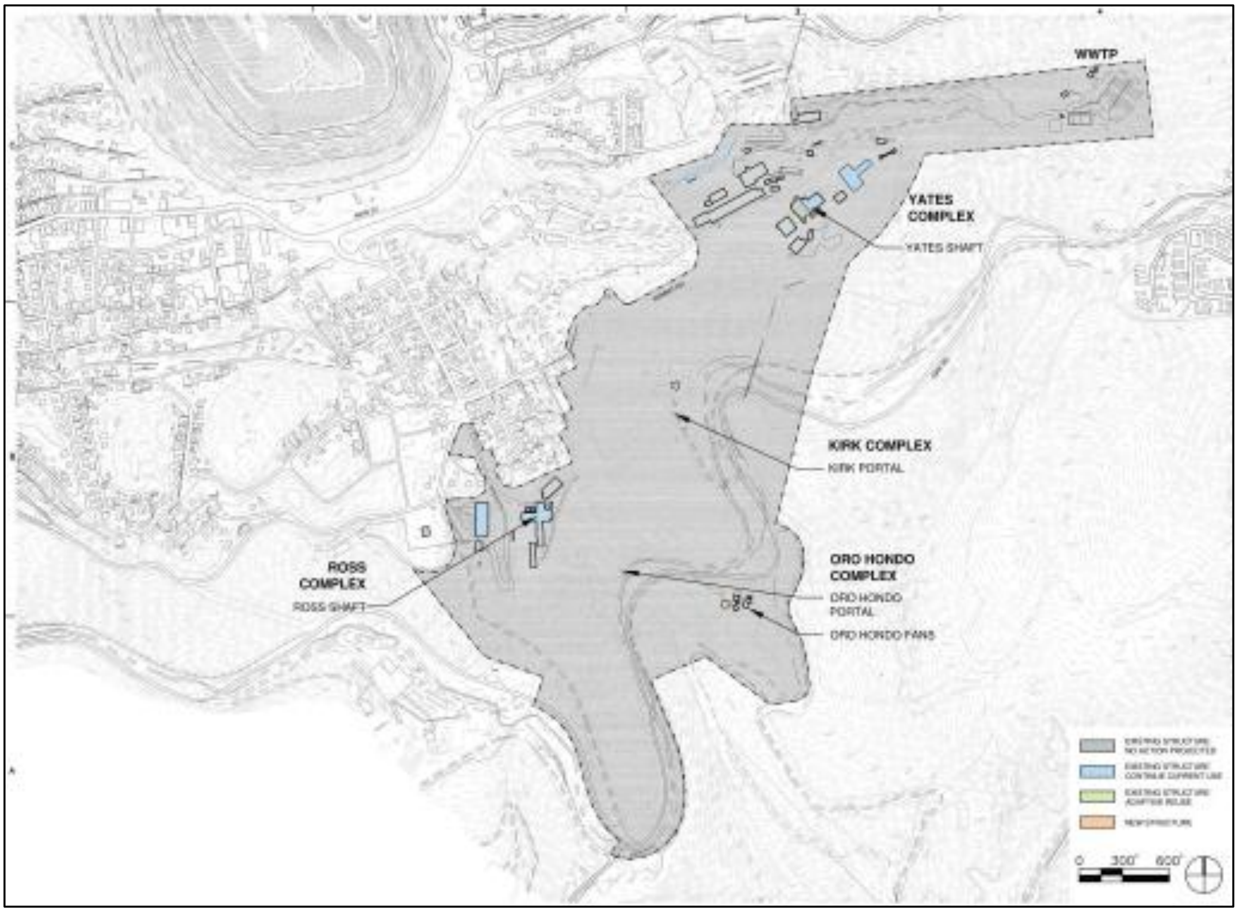

Figure 2-11: Architectural Site Plan (HDR)

The Ross Complex will house the facility construction operations, command and control center for the experiment and facility, new cryogenic compressor building, as well as continue to house the Sanford Laboratory maintenance and operations functions. Layout of surface facilities in the vicinity of the Ross Shaft is shown in **Figure 2-12**.

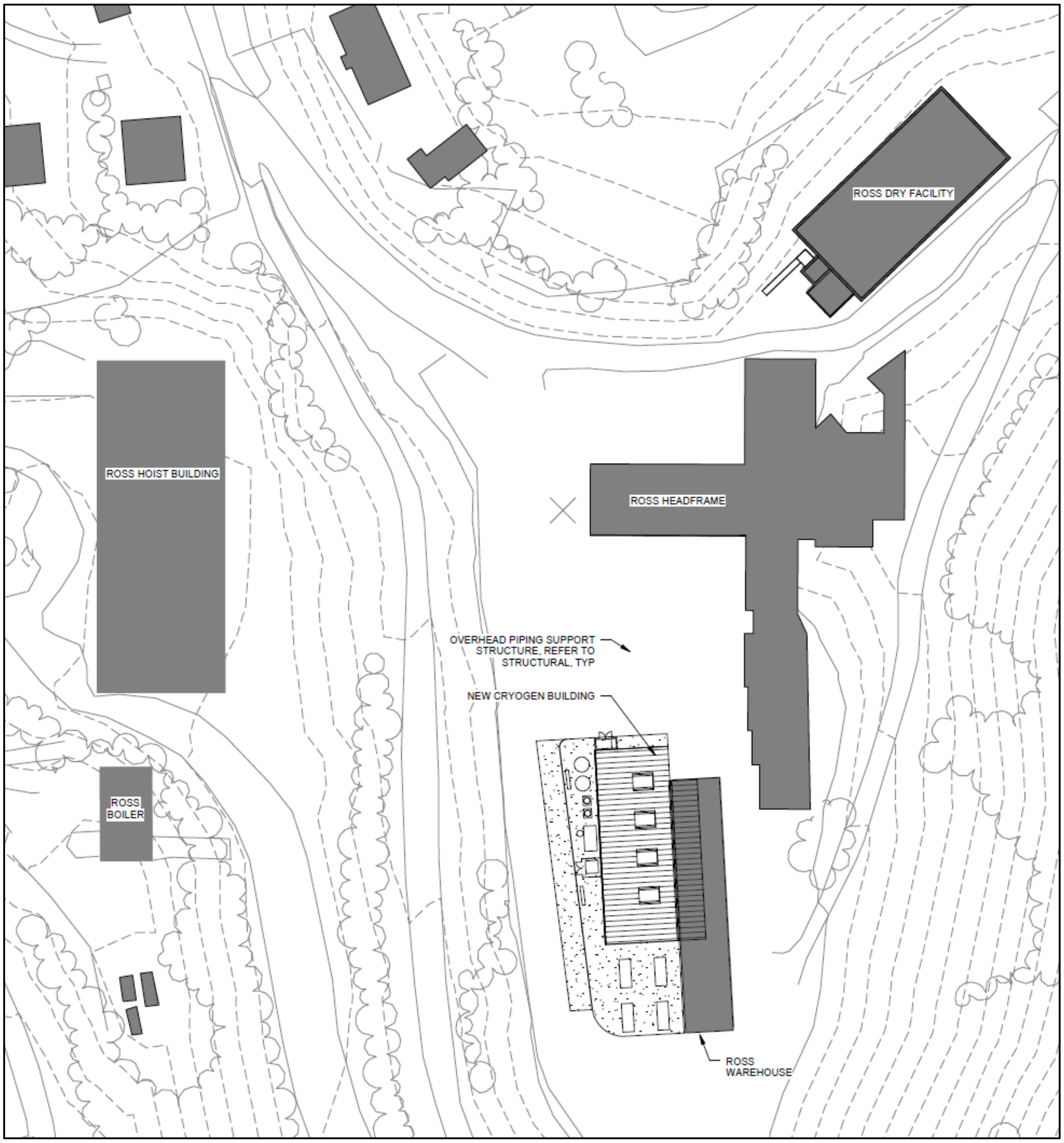

Figure 2-12: Ross Complex Architectural Site Plan (Arup)

2.4.2 Surface Buildings

Surface facilities utilized for the LBNF include those necessary for safe access and egress to the underground through the Ross Shaft, as well as spaces for temporary offices (by Sanford Laboratory). Existing buildings necessary for LBNF will be rehabilitated to code-compliance and to provide for the needs of the experiment. The only new building will be to provide space for compressors use to transfer cryogens from new receiving tank on surface to the detectors underground. The existing Ross Dry building will be modified to provide space for a surface control room and associated equipment. Much of the text below is excerpted from the 30% Preliminary Design Report provided by Arup, USA.

2.4.2.1 *Cryogenic Compressor Building*

A new building is planned to provide space for equipment to allow conversion of liquid argon and liquid nitrogen to gaseous form and compression of these gasses for delivery through the shaft to the underground where they are returned to liquid form as described in the Cryogenics Annex (docdb 10719). The location of this building was selected based on proximity to the shaft and truck accessibility, as thousands of truckloads of argon are required to fill the detectors underground.

In addition to housing nitrogen compressors inside the building, concrete slabs are provided around the building to allow for installation of argon and nitrogen receiving dewars for truck unloading, vaporizers to boil the liquids into gas, and electrical transformer to supply power to the (4) 1,500 Hp compressors, a standby generator, and cooling towers to reject heat generated through compression. All equipment except the cooling towers is provided by the Cryogenics Infrastructure Project as described in Reference here.. The architectural layout of this building and surrounding equipment is provided in **Figure 2-13**.

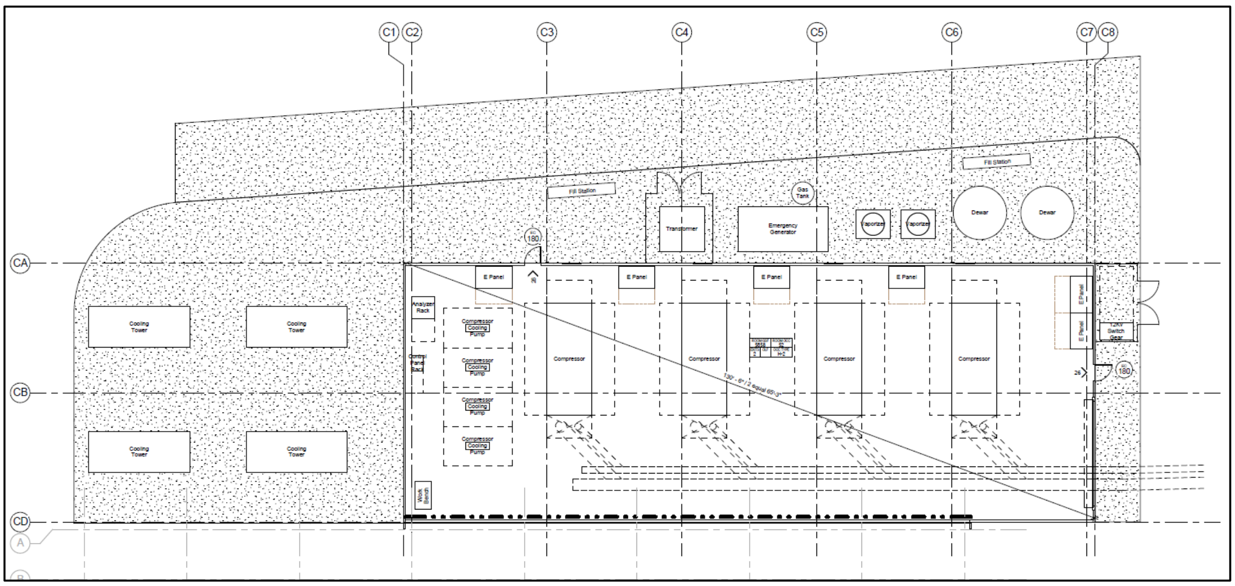

Figure 2-13: Architectural Layout of LBNF Cryogenic Compressor Building

2.4.2.1.1 Architectural

The new Cryogenic Compressor Building is a 5,700 square feet pre-engineered metal industrial building. Access will be through a 20-feet wide by 16-feet high overhead coiling insulated door. Two main doors provide egress and personnel access. Although the compressors are largely water-cooled, sufficient heat will be given off by the equipment to require large ventilation fans and intake structures as described in the article of this section. Minimal ambient light will be provided through a series of translucent panels, with supplemental overhead electric lighting.

The interior of the building will be industrial in nature, with an exposed steel frame and sub-frame carrying the pre-engineered insulated metal skin and roof panels. The interior will be painted white. The concrete slab will be left exposed and sealed.

Located immediately adjacent to the Ross Warehouse, the roof of the building will be a single-pitch shed roof that slopes away from the existing building. An added section of roof will prevent snow accumulation in the valley formed between the two buildings. This “snow shed” may be partially supported by both buildings or may be entirely supported by the new structure, which is pending further analysis. The joint between the two buildings will be filled with a flexible joint cover to prevent access by animals; however, access will be maintained to the existing roof area beneath the shed to allow maintenance. The triangular area at the ends will be filled with removable metal panels to facilitate this access. An elevation view of this arrangement is shown in **Figure 2-14**.

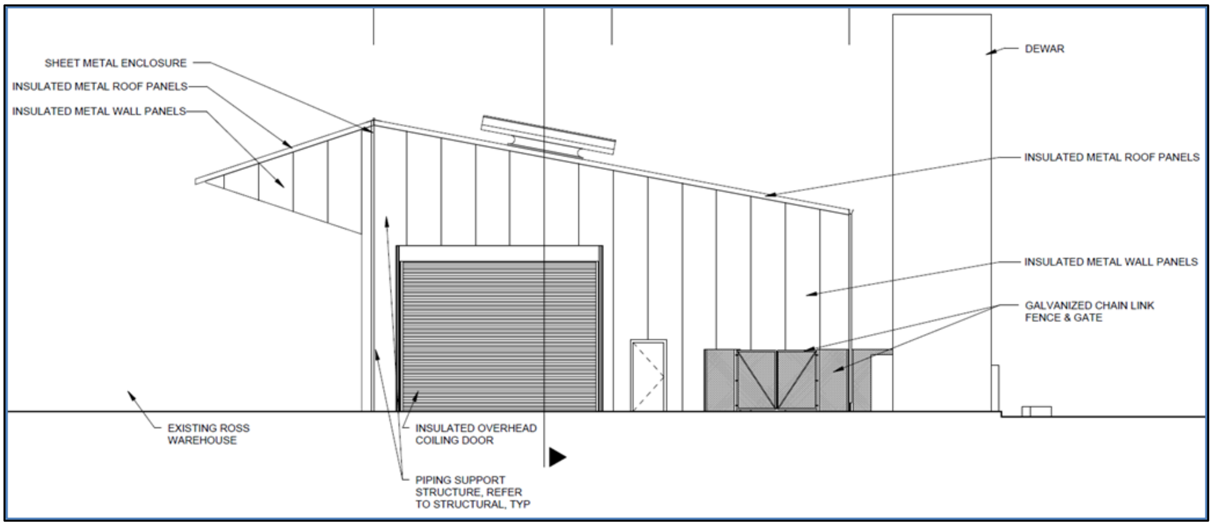

Figure 2-14: Elevation View of LBNF Cryogenic Compressor Building Showing Roof Connection to Existing Warehouse

2.4.2.1.2 Structural

The structure of the LBNF Cryogenic Compressor Building will be steel frame and truss on a slab foundation with connections to bedrock approximately 7 feet below grade. A review of the existing warehouse structure will be completed during preliminary design to determine whether the roof connection will overload the existing structure. If so, the new structure will provide structural support of the cantilevered section to avoid transferring any snow load to the existing structure.

As the design progresses, the foundation of the building and the surrounding concrete will be designed to accommodate all live and dead loads associated with the planned cryogenic equipment. At a minimum, thickened slabs with vibration isolation are expected to be provided for the compressors, and additional consideration will be given for the large cryogen dewars. The proximity of the adjacent truck delivery path to the slope also requires that consideration be given to slope stability and control.

2.4.2.1.3 Mechanical

Based on preliminary load information provided by LBNF, the compressors will require a ventilation rate of 120,000 CFM when outdoor air is 90 F (32.2 C). This ventilation rate will be reduced when outdoor temperature are less than 90 F. Exhaust ventilation will be provided by 4 wall propeller fans, equipped with variable frequency drives. The position of the building and compressor locations dictate that these exhaust fans should be located on the west wall, one exhaust fan per compressor. The makeup air will be introduced through the roof, via direct fired makeup air furnaces and gravity intake hoods, both located on the roof.

The exhaust fan VFDs and makeup air units shall be interlocked to maintain a 40 – 100 F (4.4 – 37.7 C) temperature in the building via indoor temperature sensor(s). At least one compressor is expected to operate at all times, so most heat will come from this operation and the air heaters will only supplement as needed.

Compressor cooling is done by circulating water from the compressors to four cooling towers located outside of the building. Cooling towers provide the ability to reject heat more efficiently than other heat exchange systems, but also require special consideration in cold climates such as Lead, SD. Controls will be installed to avoid damage due to freezing conditions if the compressors are not running.

2.4.2.1.4 Electrical

The new Cryogenic Compressor Building well be powered by a 12.47 kV feeder from the Ross Substation. Outside of this building on the north end will be a 12 kV substation containing a 6 MVA transformer with feed-through bushings and primary fuses. The feed-through bushings will allow a 12 kV feed to the crusher building if necessary. Arc Flash protection will be provided by the feeder relay/breaker in the Ross Substation.

The secondary voltage of the Cryogen Substation transformer will be 4.16 kV or as required by the Cryogen compressor equipment. Medium voltage electrical equipment in the Cryogenic Compressor building will feed motor control equipment for the four compressors and any other medium voltage loads. Dry transformers will provide 480 and 120/208 V for smaller loads, lighting and outlets in the building. Surge suppression will be provided in this distribution equipment.

A 480V diesel generator will provide emergency power for control equipment, lighting and all 120/208V loads. This generator will be sized based on equipment to be serviced and is anticipated to about 50kW.

Lighting will be provided inside the building with high-bay style LED fixtures. Lighting will be provided outside the building to support the delivery of cryogenic liquids to the building as well as the operation of equipment outside the building. Emergency egress and exit lighting will utilize fixtures with integral batteries.

A digital, addressable, microprocessor based, electrically supervised fire management type system will be provided complete with central processing unit, power supplies, remote annunciators, auto dialer for monitoring company connection, audible and visual signal devices, manual stations, automatic devices including ionization smoke detectors, combination fixed temperature/rate of rise detectors, etc. as required. Alarm connection will allow monitoring of other campus systems through the Cyberinfrastructure system.

2.4.2.1.5 Plumbing

A 4” or 6” water for fire suppression and industrial use shall enter the building at the southwest corner. The fire suppression requirements have not yet been determined. Water will be required to fill the cooling towers and the cooling tower pumped water system. Pumps and plumbing will be provided to circulate cooling water between the compressors and cooling towers. Containment curbs will be provided to capture leaks and spill and a drain system will be connected to the local sanitary sewage for discharge as long as no environmental contaminants are within the containment.

2.4.2.2 Ross Dry

The Ross Dry building is in use by the Sanford Laboratory to provide office and meeting space in addition to men's and women's dry facilities. A portion of an existing meeting space within this building will be modified to allow the installation of a control room for both facility and experiment control.

The exterior of the Ross Dry is shown in **Figure 2-15**. The location of the new command and control center is shown in Figure 2-16.

Figure 2-15: Photo of Ross Dry Exterior HDR

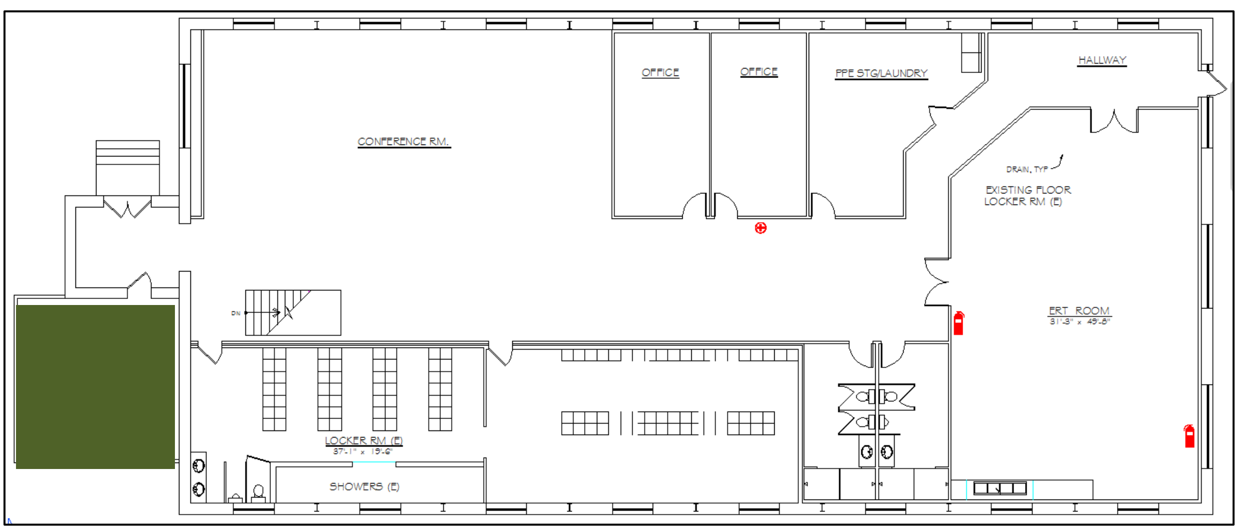

Figure 2-16: Location of New Command and Control Center (Sanford Lab)

The current building does not have a central HVAC system. The control room will be heated and cooled utilizing small split system heat pump(s). An evaporator fan coil unit shall be located at the ceiling, with a condensing unit located outside on grade. Outdoor unit shall be capable of operation down to -10 F if necessary to cool a server room.

The Control Room addition to the Ross Dry building will be powered from a new 120/208V electrical panel in the Control Room. This panel will be fed from an existing panel in the Ross Dry building and will contain surge suppression for the control room equipment. Lighting will be provided for the Control room with dimmable 2x4 LED light fixtures.

A digital, addressable, microprocessor based, electrically supervised fire management type system will be provided complete with central processing unit, power supplies, remote annunciators, auto dialer for monitoring company connection, audible and visual signal devices, manual stations, automatic devices including ionization smoke detectors, combination fixed temperature/rate of rise detectors, etc. as required. Alarm connection will allow monitoring of other campus systems through the Cyberinfrastructure system. An existing 4” water line will be used to provide sprinkler protection through a dry, pre-action system in the control room.

The Control Room located in the Ross Dry Building is the point of interface at the surface to the experiments at the 4850 level from a monitoring and data collection/storage stand point. Given this use case, and the need for network equipment and peripheral devices in this space to support a 24/7 operation, the design must anticipate high availability of the network equipment installed here and provide an environmentally controlled Communications Room. An existing room in the basement will accommodate at least four equipment racks or cabinets. This will enable adequate storage area network server space, network equipment space, and campus backbone terminations space to be accounted for.

2.4.2.3 Ross Headframe and Hoist Buildings

The headframe and hoist buildings at the Ross Campus provide services for LBNF use. The Ross Headframe Building will be the main entry point for construction activities as well as the ongoing operations and maintenance functions. Gas pipe from the LBNF Cryogenic Compressor Building will pass through this building to get to the shaft. The Ross Headframe is shown in Figure 2-17 with the warehouse building in the foreground.

Figure 2-17: Photo of Ross Headframe (HDR)

The Ross Hoist building houses the existing Sanford Lab fiberoptic network connections. All connections for LBNF will derive from this building. This building has connection to an underground tunnel known as the Ross Steam tunnel. This tunnel leads from the Ross Boiler Building on the surface to the Ross shaft at approximately 70' below the shaft collar. In addition to fiberoptic lines, all power for both the underground and the Cryogenic Compressor Building will pass through this tunnel from the Ross Substation.

2.4.2.4 Ross Crusher Building

The existing Ross Crusher Building, as shown in **Figure 2-18** is a high bay space that contains rock crushing equipment that will be used for construction operations. The exterior of the building will be repaired to create a warm, usable shell. The upgrade of the existing crusher equipment is part of the waste rock handling work scope and not part of the building rehabilitation.

Figure 2-18: Photo of Ross Crusher Exterior (HDR)

Building rehabilitation work includes installation of fire suppression systems, improved lighting and heating, and miscellaneous minor plumbing and power upgrades. All other work associated with the Ross Crusher Building is captured in the waste rock handling scope of work.

2.4.3 New Surface Infrastructure

Surface infrastructure includes surface structures such as retaining walls and parking lots, as well as utilities to service both buildings and underground areas. Existing infrastructure requires both rehabilitation as well as upgrading to meet code requirements and LBNF needs. The experiment needs were documented in the requirements found in *LBNF Requirements Document* [8], and combined with facility needs for the design detailed in the Arup 30% Preliminary Design Report (docdb 10756).

2.4.3.1 Roads and Access

No new roads or parking lots are required for LBNF at the Sanford Laboratory. The Ross Complex site will require minor demolition of power lines and a fire hydrant that are no longer used to provide adequate accessibility for truck traffic to the new Cryogenic Compressor Building. The truck delivery route is shown in **Figure 2-19**. An existing space will be designated for handicap parking adjacent to the Ross Dry Building. Additional road work is required for truck transportation of waste rock, as described in the waste rock handling section.

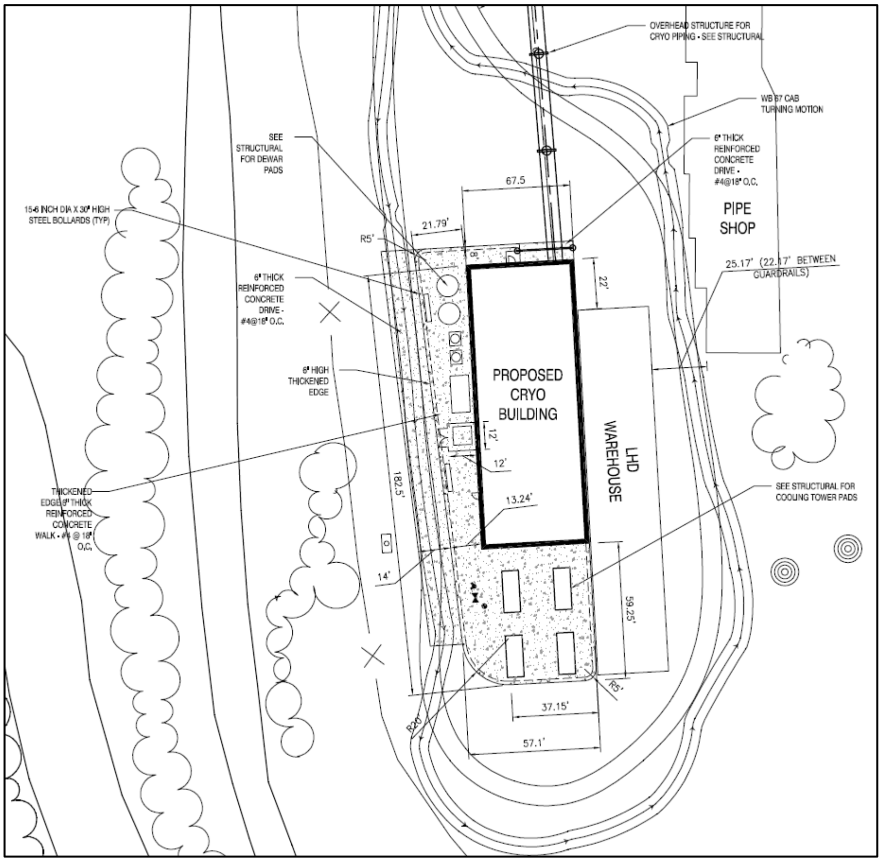

Figure 2-19: Truck Turning Diagram for Cryogen Delivery at the Ross Site

2.4.4 Surface Electrical Infrastructure

Power for all LBNF equipment will derive from the Ross Substation. Two of the four existing 12.47 kV breakers would be refurbished by factory technicians. These breakers would then feed the LBNF Caverns on the 4850L and the Cryogenic Compressor Building on the surface. One spare breaker will remain available in this switch gear. Cables will be routed from the substation across an existing structure to the steam tunnel, which is adjacent to the existing Ross Boiler Building. The cables would be routed through conduits on the floor of this tunnel to the Ross Shaft, where some cables would go down the shaft to the 4850L while others would go up to the headframe and across the cryogenic gas pipe structure to the Cryogenic Compressor Building as shown in **Figure 2-20.**

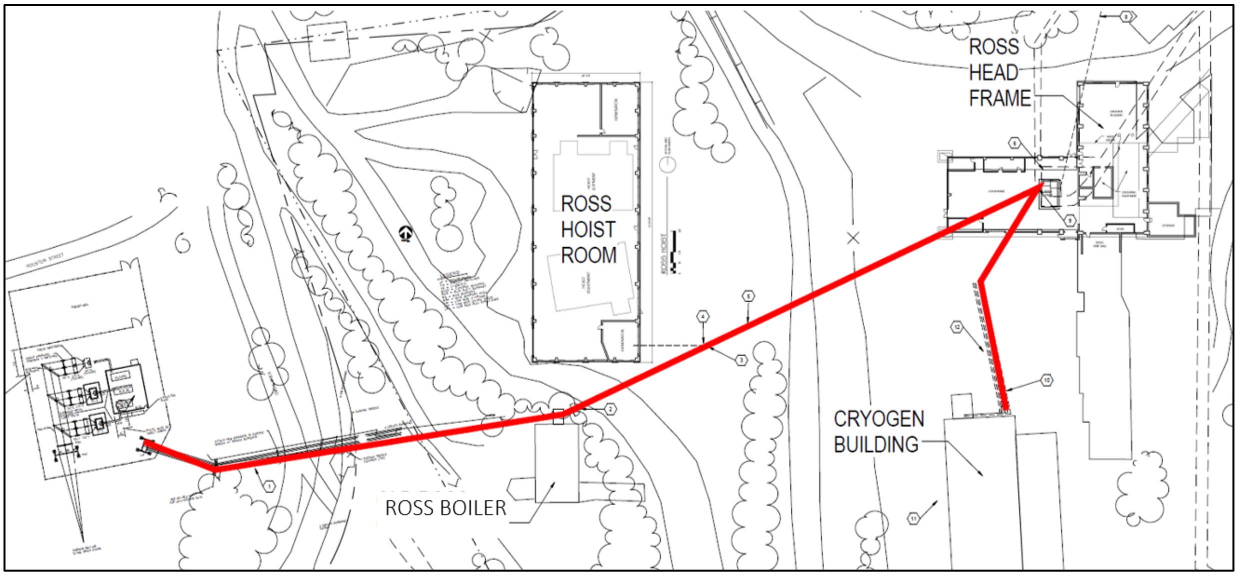

Figure 2-20: Supply Power for LBNF (Arup)

Table 2-1: Power Requirements for the LAr-FD Experiment and Facility

Underground Electrical Load by Area	kW	kW
Cryostat 1&2 Detector Electronics	450	
Cryostat 1&2 Argon Pumps	98	
Cryostat 1&2 CF	350	898
Cryostat 3&4 Detector Electronics	450	
Cryostat 3&4 Argon Pumps	98	
Cryostat 3&4 CF	342	890
Central Utility Cavern - Detector Cryogenics	956	
Central Utility Cavern - DAQ	36	
Central Utility Cavern - CF	753	1745
Spray Chamber	165	
Maintenance/Assembly Shops (2)	84	
Drifts	152	401
Total =		3934
Aggregate Demand Factor	x	0.736
Demand Total =		**2894**

Emergency/Standby Generator =	848
Aggregate Demand Factor =	0.393
Generator Demand Total =	**334**

Underground Load by Function	kW
Detector	2088
CF	1846
Total =	3934
Aggregate Demand Factor	0.736
Demand Total =	**2894**

Surface Electrical Load	kW
Cryogen Building	5000
Control Room	250
Emergency/Standby Generator	50
Total Surface Load	**5300**

Temporary Electrical Load	kW
Construction Power	**1653**
Emergency/Standby Power	**699**

2.4.4.1 Cyberinfrastructure

On the overall site, communications infrastructure is required for voice/data communications, security, facility management system, and fire alarm system. The underground systems will be tied to the corresponding surface systems. Redundant underground communications will be provided through new backbone cables in the Ross Shafts and existing fiber through the Yates Shaft interconnected at the 4850L. The campus fiber and copper backbone network will be upgraded and extended to the existing Ross Hoist Building telecommunications closet. The Ross Campus will be the main IT source, with the Yates as backup.

2.4.4.2 Surface Mechanical and HVAC

Ventilation for the underground systems is provided by equipment at the Ross and Yates Campuses. Heating of the supplied air is required to prevent ice formation in the Ross and Yates Shafts during cold weather. The Sanford Lab recently upgraded the air heaters at both shafts, which is expected to be adequate for operation of LBNF. Temporary heating may be necessary during excavation due to higher intake flow demands, but this is a construction requirement handled by general conditions in a construction contract and not part of the design scope.

2.4.4.3 Surface Plumbing Systems

The only modification to existing surface plumbing systems is connection to water supply, sanitary sewer, and natural gas for fire protection, compressor cooling water, and heat at both the LBNF Cryogenic Compressor Building and the Ross Dry building as described below.

2.4.4.3.1 Fire Protection Systems

Both the new Cryogenic Compressor Building and the control room at the Ross Dry Building will be sprinklered. The building fire protection system for these buildings will be supplied from the water distribution system on site. The system will be designed in accordance with NFPA-13 guidelines, with fire sprinkler hazard classifications selected to suit the building function. Underground laboratories will be supplied fire water from the existing gravity water distribution system originating at the surface Ross Complex. Fire water piping will be routed to the shaft collar for interface with the underground piping installation.

Given the relatively low water pressure available on the Ross Campus, a new fire pump system will be provided to serve the structures. This system will include two 1,000-gallon per minute (GPM) electric fire pumps supplied with stand-by power. This system will include all required accessories such as jockey pumps, flow test meters, flow test headers, controllers, etc. The system will reside in the Ross Dry Building. New fire pumps will be UL/FM approved and fully compliant with NFPA 20. Piping for the sprinkler and standpipe systems will be Schedule 40 black steel with flanged, grooved or threaded fittings. Two fire pumps, each capable of 100% of the required flow, will be provided.

2.4.4.3.2 Gas Fuel System

Natural gas is used as the primary fuel in the shaft ventilation systems. Dual fuel systems are not included, though the Black Hills area is near the end of a natural gas pipeline from North Dakota. Service is reliable but is served on an interruptible basis for large loads during adverse weather conditions. Loads below approximately 2,500 MBH (thousands of BTU’s per hour) per customer are typically allowed to be served on a firm basis. The periods of interruption are typically one to several days.

Natural gas will be distributed to the heating, ventilation, and air conditioning (HVAC) mechanical equipment requiring natural gas at both the LBNF Cryogenic Compressor Building and Ross Dry Building. The low pressure gas shall be distributed inside the buildings at 7 inch to 11 inch water column. The primary design criteria use the 2009 International Plumbing Code and NFPA-54, including the applicable state and city amendments.

Natural gas will be distributed within buildings in Schedule 40 black steel piping with black iron welded fittings. The natural gas lines serving the facility will be sized for the current building program with an additional anticipated load of 20% for renovation flexibility.

3 UNDERGROUND EXCAVATION

The main excavated spaces necessary to support the LBNF experiment are a combination of excavations required for the experiment and those believed to be required for constructability. Experimental spaces on the 4850L include the detector cavities, several drifts for access and utility routing, and the central utility cavern. Spaces identified as likely necessary for the excavation subcontractor include mucking drifts connected to the Ross Shaft to enable waste rock handling and equipment assembly shops to provide space to assemble and maintain excavation equipment underground. In addition, a spray chamber is provided for heat rejection from the chilled water system. All spaces are identified on the 30% Preliminary Design excavation drawings produced by Arup [9]**.** The spaces are shown below in **Figure 3-1**.

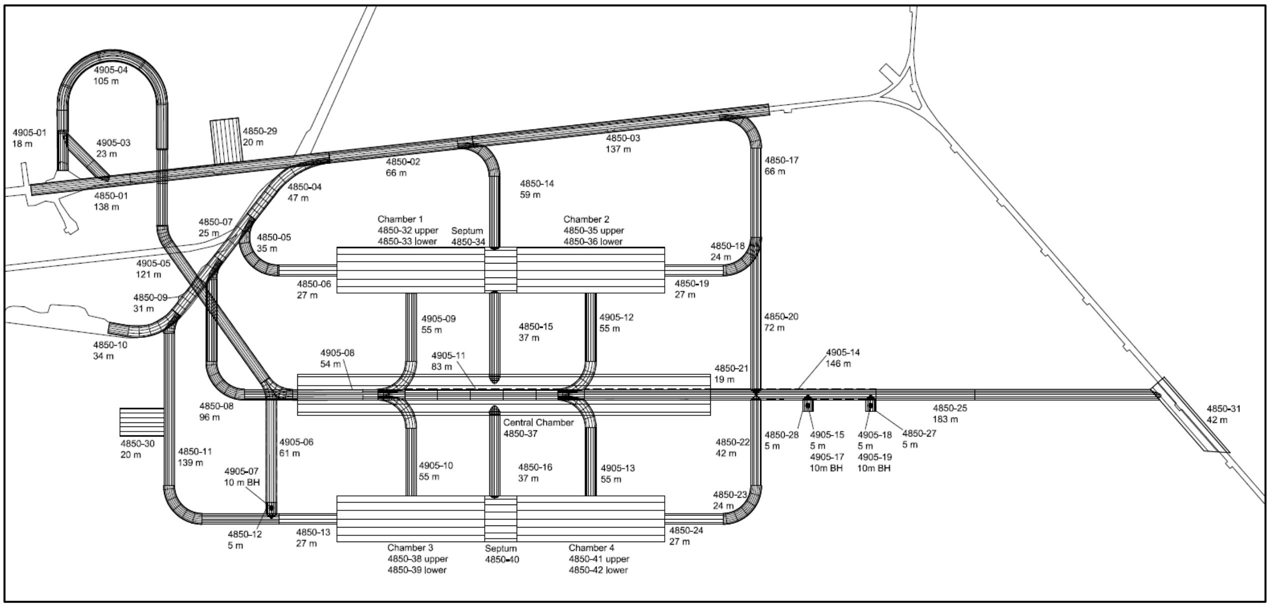

Figure 3-1: Spaces Required for LBNF at 4850 (Sanford Lab)

3.1 LBNF Cavities

The required experimental spaces were defined through interaction with the DUNE design team and are documented in the *LBNF Requirements Document* [8]. The size and depth of the LBNF cavities were prescribed to suit the scientific needs of the experiment. The ten overall main cavern sizes are shown graphically in **Figure 3-2.** The DUNE experiment will be housed in four detector pits within two main caverns at the 4850L. Siting deep underground is required to shield from cosmic rays, as detailed in *Report on the Depth Requirements for a Massive Detector at Homestake* [10]. The 4850L is deeper than what is absolutely required, but is used because of existing access at this level.

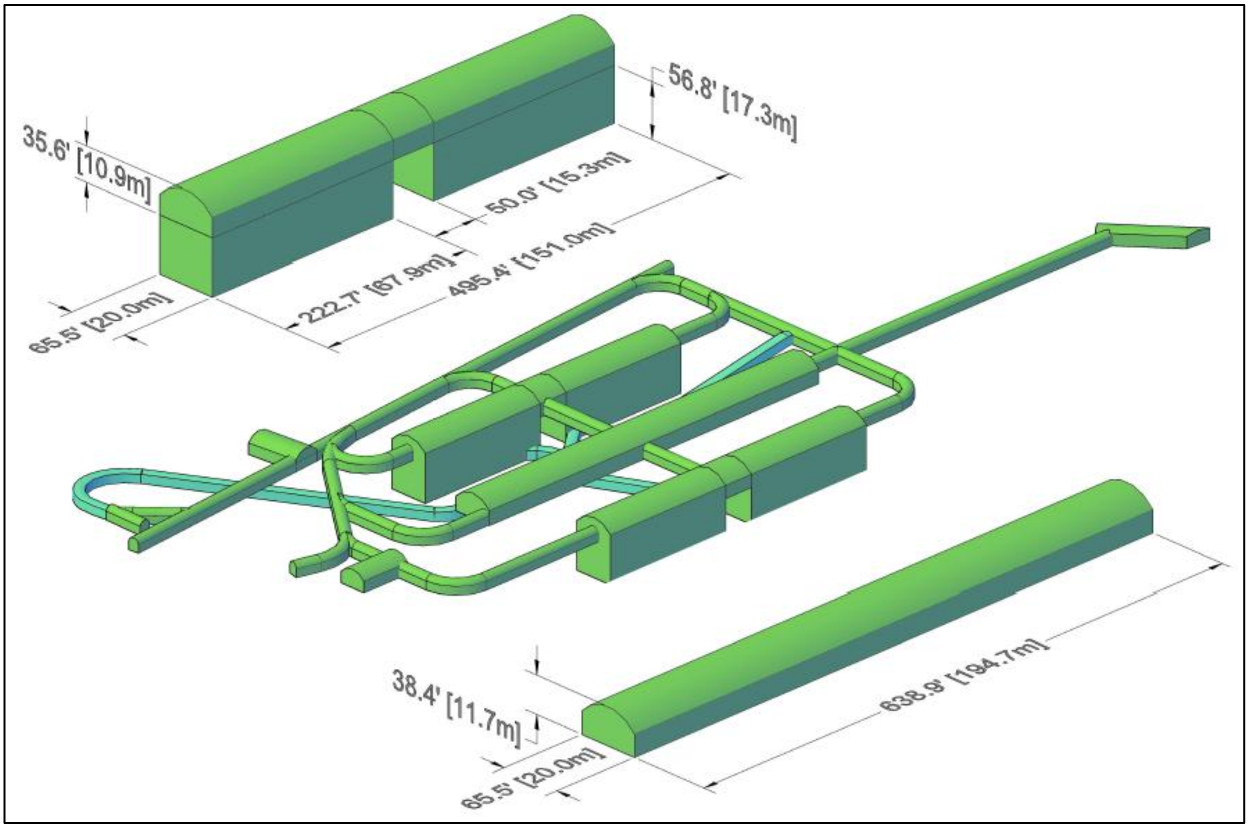

Figure 3-2: Dimensions of the Main LBNF Cavern Excavations (Final dimensions may be smaller in size) (Sanford Lab)

The limits on size for the detector are determined by rock strength and the limits on the ability to produce large dimension anode and cathode plane arrays. Space occupied by the vessel liner, and an intentional exclusion zone reduce the fiducial volume of the detector below the volume of the excavation. Current assessment of rock quality indicates that a cavity of this size is reasonable with the rock quality assumed for this formation.

Preliminary modeling of the proposed excavations included 2D and 3D numerical modeling. The intact rock strength and joint strength had the greatest impact according to the 2D modeling, and 3D modeling confirmed that the complex geometry is possible.

The LBNF caverns will be excavated using modern drill and blast techniques, in phases from the top down. Excavation accesses to the crown of the cavity and to the base of the excavation will be via ramps. The upper ramp will begin at the access, while the lower ramp will begin further toward the Ross shaft. This lower ramp is necessary for outfitting the experiment as well as removal of waste rock. A raise bore will be pulled to the crown from the lower ramp. The cavity will then be excavated in lifts, with ground support installed as excavation progresses (see **Figure 3-3**). Given the size of the LAr-FD cavity excavation, the presence of structural features, potential for overstress zones and critical requirements for long–term stability, special attention will be paid to controlled drilling and precision blasting techniques. This will minimize overbreak and create smooth, stable walls as much as possible.

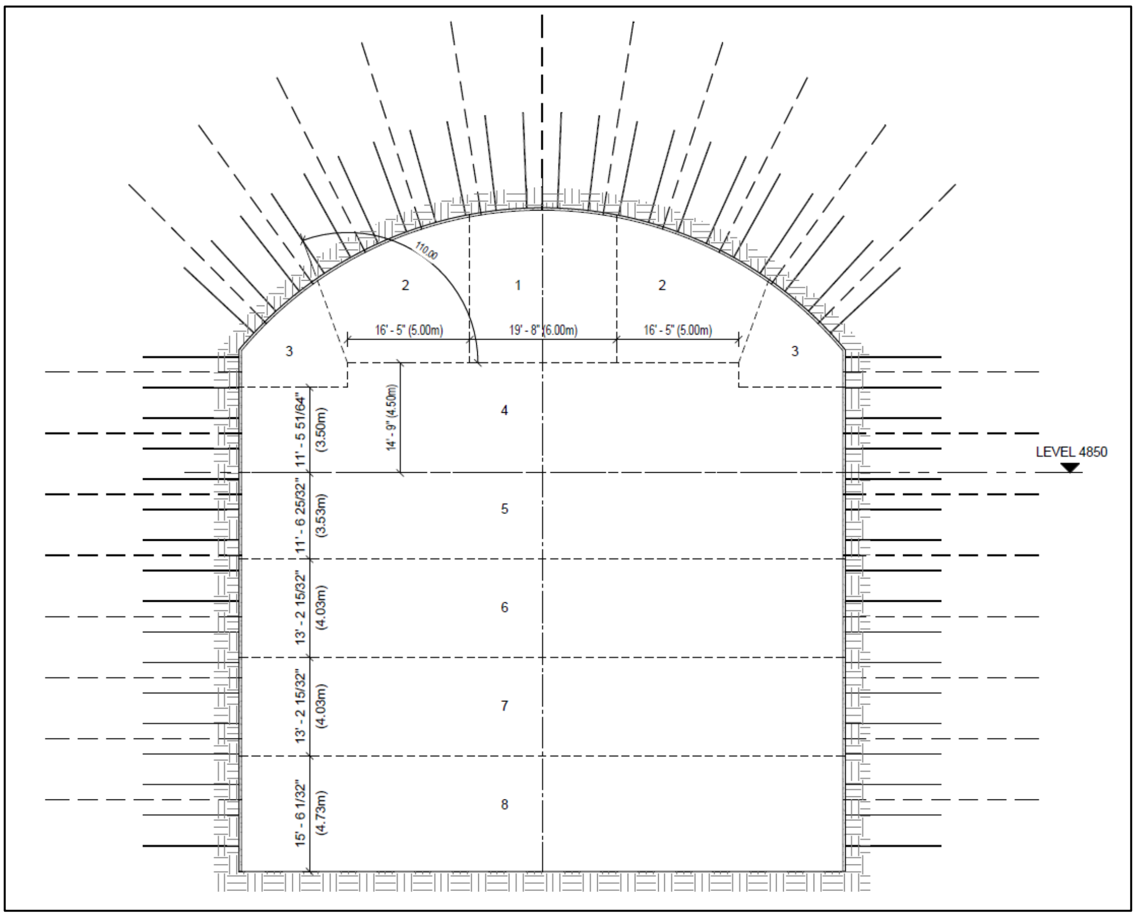

Figure 3-3: LBNF Cavern Excavation Sequence (Arup)

The LAr-FD cavity and drifts will be supported using galvanized rock bolts/cables, wire mesh, and shotcrete for a life of 30 years. The floor of the cavity is not anticipated to require support.

A groundwater drainage system will be placed behind the shotcrete in the arch and walls of the LAr-FD cavity rock excavation. This drain system will collect groundwater (native) seepage and eliminate the potential for hydrostatic pressure build-up behind the shotcrete. Channels will be placed in the concrete invert to drain groundwater to the sump system.

3.1.1 Structural and Cranes

The LBNF caverns require monorail cranes to facilitate the construction of the detector components. Rock bolts will be coordinated with the excavation contractor to provide anchorage to support these monorails.

3.2 LBNF Central Utility Cavern

LBNF requires spaces for cryogenic equipment outside of the detector caverns. These requirements are combined with those for the conventional facilities' utilities in an independent central utility cavern. This area will house the experiment's cryogen system, electrical equipment to supply power for facility and experiment needs, sump pump access and controls, fire sprinkler room, air handling units (AHUs), chilled water system, and exhaust ducting. The centralized location minimizes overall utility distribution costs. Isolating the utilities from the experiment simplifies electrical ground isolation to avoid interference with sensitive detector electronics, and also provides the opportunity to optimize ventilation to control heat emanating from the equipment in the central utility caverns.

3.3 Access/Egress Drifts

in order to accommodate deliveries, the drift connections from the Ross Shaft to new excavations required for LBNF will be optimized to accommodate the maximum load size possible through the shaft plus the utilities required to service the facility. When this document was written, an assumed size of 5m wide by 6m tall is used for all access and egress drifts. All new excavations, or drifts enlarged for LBNF will be provided with a shotcrete wall (rib) and ceiling (back) and a concrete floor (sill).

3.4 Excavation Sequencing

A key goal of both LBNF and DUNE is to complete construction of one 10-kT detector as soon as possible. To facilitate this, the excavation will be sequenced to allow DUNE to begin installation of a cryostat in the first detector pit while excavation continues. A temporary wall will be built in the detector installation laydown space between detector pits to isolate one area from another. This wall must be of sturdy construction to withstand air shock waves associated with drill and blast type construction. Further evaluation of vibration limits and controls must be considered as the design advances to avoid damaging the cryostat during assembly.

In addition to controlling the impacts from blasting, logistical coordination is a key concern with a sequenced excavation allowing cryostat construction concurrent with excavation. Most experiment components will be delivered through the Yates Shaft, leaving the Ross shaft dedicated for excavation and other construction. The area between the Governor's Corner and the experiment, however, will require interfacing between delivery of experiment equipment, delivery of ground support and explosives, and transportation of excavated material. The contractor will be tasked to determine whether "traffic control" at this intersection is performed with electronic signaling or personnel.

Most excavated material will travel through a mucking ramp starting at the base of each detector pit and ending at the waste dump near the Ross Shaft. This route is completely independent of all other traffic and includes a separate ventilation stream to keep diesel exhaust from other occupied spaces. During times when excavation is establishing the upper sections of the caverns and developing a means of dumping excavated material to this lower elevation, material will need to be transported at the 4850L. This not only introduces concerns with interference between experiment deliveries and rock haulage, but also means that both diesel exhaust and dust can impact the “clean” experiment pit where construction is occurring for the first cryostat. Dust will need to be controlled using water throughout all excavation, but during these times it will be more critical. Diesel fume controls will be further evaluated as the design progresses to determine the best means of controlling them.

Delivery of cryostat components to the individual pits can be accomplished in one of two ways. All materials are delivered through the shafts to the 4850L, which is ~15m above the base of the pits. During construction of the first cryostat, while excavation continues in the other areas, all materials will be delivered to the detector installation laydown area between the first and second detector pits. An overhead crane will be used to lower this material into the pits. This crane is required for installation of detector component within the cryostat, so is not additional equipment. Further schedule analysis will determine whether the construction of the second cryostat will also be performed in this way. All excavation will be completed before any construction is required in the third and fourth detector pits, providing the opportunity to use the excavation mucking ramp for delivery of cryostat components. This ramp has been designed at a steep 15% grade as of the 30% preliminary design to get it deep enough to pass below existing excavations in the shortest distance possible. Further coordination will be required as the design advances to determine if the slope should be reduced to make the ramp more useful for operations other than excavation.

3.5 Interfaces between DUNE, Cryogenics and Excavation

There are several points at which the experiment and the facility interface closely. These are managed through discussions between DUNE design team, the Cryogenic Infrastructure Project team, the Conventional Facilities project team, and design consultants.

- The LBNF cryostat is a freestanding structure requiring infrequent access for inspection around the vessel. Low tolerance control in excavation will impact the cost of providing access to inspect this vessel.
- The utility spaces to house the cryogen system are directly influenced by the size of the cryogen system equipment.
- The size and construction sequencing of the detector pits are critical to the experiment strategy

4 UNDERGROUND INFRASTRUCTURE

The requirements for underground infrastructure for the LBNF Project will be satisfied by a combination of existing infrastructure, improvements to those systems, and development of new infrastructure to suit specific needs. The Project must consider the other tenants underground at Sanford Laboratory for which infrastructure is required, including both the existing Davis Campus experiments and the Ross Campus Experiments. The Ross campus experiments in particular are in relatively close proximity (~150m) to LBNF.

The systems must support the LBNF Conventional Facilities (CF) construction activities, Cryogenic Infrastructure installaiton, DUNE experiment installation, and operations of both CF Equipment and the experiment. These three scenarios were analyzed and the most demanding requirements chosen from each situation were used to define the requirements for design.

Some of the Sanford Laboratory infrastructure that requires upgrading for LBNF will be rehabilitated prior to the beginning of LBNF construction funding. This includes Ross Shaft rehabilitation, Yates Shaft focused maintenance and repair, and ground support activities at the 4850L between the Yates and Ross Shafts. Additional discussion of these items is included in Section **5**.

The conceptual underground infrastructure design for LBNF has been performed by several entities. The primary designer referenced in this document is Arup, USA. Arup's scope includes utility provisions and fire/life safety (FLS) strategy, covering infrastructure from the surface through the shafts and drifts, to the cavity excavations for the experiment. Utility infrastructure includes fire/life safety systems, permanent ventilation guidance, HVAC, power, plumbing systems, communications infrastructure, lighting and controls, per the experimental utility requirements provided by DUNE and through coordination with LBNF, Sanford Laboratory and the excavation and surface design teams. The design is described in Arup's *LBNF 30% Preliminary Design Report for LAr at 4850L* [11] and in the conceptual design drawings [11]. This section summarizes the work done by Arup and utilizes information from that report.

Shaft rehabilitation and waste rock handling design were previously provided by Arup for the DUSEL PDR. This section uses excerpts from the DUSEL *Preliminary Design Report,* Chapter 5.4. The research supporting this work took place in whole or in part at the Sanford Underground Laboratory at Homestake in Lead, South Dakota. Funding for this work was provided by the National Science Foundation through Cooperative Agreements PHY-0717003 and PHY-0940801. The assistance of the Sanford Underground Laboratory at Homestake and its personnel in providing physical access and general logistical and technical support is acknowledged.

4.1 Fire/Life Safety Systems

Life safety is a significant design criterion for underground facilities, focusing on events that could impact the ability to safely escape, or if escape is not immediately possible, isolate people from events underground. Design for fire events includes both preventing spread of fire and removing smoke and/or cryogenic gasses through the ventilation system. The evaluation and establishment of requirements for cryogenic gas removal is performed by the cryogenic group and provided to CF.

Life safety requirements were identified and the design developed by Arup, utilizing applicable codes and standards, including NFPA 520: Standard on Subterranean Spaces, which requires adequate egress in the event of an emergency. Facility fire detection and suppression systems, as well as personnel occupancy requirements are defined in accordance with NFPA 101: Life Safety Code. The design was reviewed by Aon Risk Solutions and the recommendations documented in *Fire Protection/Life Safety Assessment for the Conceptual Design of the Far Site of the Long Baseline Neutrino Experiment.* Due to the unique nature of the experiment and its' location, a number of potential variances will require approval from the Authority Having Jurisdiction (AHJ). Significant examples include use of elevators for egress and use of drifts as air "ducts". The AHJ for Lead, SD is familiar with the facility nd the project, and is expected to provide reasonable and timely feedback for proposed variances.

Based on data provided by Sanford Laboratory, the maximum occupant load of the 4850L will be controlled to 144 occupants following completion of the Ross Shaft Rehabilitation. This can support the anticipated 42 Underground Operations staff, 50 science staff for LBNF (during installation), and 20 science staff associated with the existing experiments.

Compartmentation will be needed for egress routes to separate them from adjacent spaces to limit the horizontal and vertical spread of fire and smoke. Use of compartmentation will help reduce the likelihood of fire and smoke spreading from the area of the fire origin to other areas or compartments. Compartmentation will also help limit the spread of other materials such as, cryogenic gases, leaks and spills. This results in design criteria of a minimum -four-hour fire separation between the LBNF cavities and adjacent drifts, while all rooms that connect directly to the egress drift at 4850L, as well as the shafts, will have two-hour minimum fire separation.

4.2 Egress and Areas of Refuge

The evacuation strategy for occupants at the 4850L is to egress directly to the Ross Hoist/Cage (or Yates Hoist/Cage if the Ross Hoist/Cage is not working or inaccessible) to evacuate to grade. If occupants are subjected to untenable conditions within the egress route, then they will need to evacuate to the alternate hoist/cage or to the Refuge Chamber. There will be a minimum of two ways out of each LBNF Cavity and areas of high hazard. Once in a drift (exit route) there will be at least two directions to escape from any location leading to a choice of exit hoist/cage.

A Refuge Chamber provides a protected environment for occupants during an emergency event, such as a fire or cryogen leak. The existing Refuge Chamber is strategically located within the 4850L such that the travel distance to the Refuge Chamber is limited to within the NFPA 520 maximum travel distance of 2,000 ft. The Refuge Chamber will be upgraded by the Sanford Lab to provide enough food, water, and breathing air to support up to 144 people for up to 96 hours. Refuge Chamber area calculations use a baseline area of 10 sf/person, derived from NFPA 520. Carbon dioxide scrubbers and oxygen bottle clean and replenish the air. Food and water are provided in prepackaged containers designed specifically for this purpose for use in the mining industry.

4.2.1 Emergency Systems

Systems will be installed to facilitate egress for life safety and protect personnel and equipment during emergencies. This includes fire suppressions systems, smoke control, alarm and detection systems, two-way voice communication, and emergency lighting. The details of these systems are described in the sections below.

4.2.2 Shafts and Hoists

The Ross and Yates Shafts provide the only access from the surface to the underground, and are therefore critical to the function of the Facility. Both shafts provide service from the surface to the 4850L, though not every intermediate level is serviced from both shafts. The shafts also provide a path for all utilities from the surface to the underground.

The Ross and Yates Shafts were both installed in the 1930s and have operated since installation. These shafts, along with their furnishings, hoists, and cages, were well maintained during mining operations, but have experienced some deterioration as described in this section. A complete assessment of the Ross and Yates shafts was conducted for the DUSEL Project, and is documented in the Arup *Preliminary Infrastructure Assessment Report* (DUSEL PDR Appendix 5.M).

4.2.3 Ross Shaft

The Ross Shaft will be used for facility construction, including waste rock removal, routine facility maintenance, and secondary egress path for the finished underground campuses. It will also be used for LBNF experiment primary access. Excavation for LBNF cannot begin until the Ross Shaft is rehabilitated by the Sanford Lab.

The Ross Shaft is rectangular in shape—14 ft 0 in (4.27 m) by 19 ft 3 in (5.87 m), measured to the outside of the set steel. The shaft collar is at elevation 5,354.88 ft (1,632.17 m) and the 5000L is the bottom level at elevation 277.70 ft (84.64 m) above sea level. Service is provided to 29 levels and five skip loading pockets. The shaft is divided into seven compartments: cage, counterweight, north skip, south skip, pipe, utility, and ladder way. See

Figure 4-1below showing shaft layout.

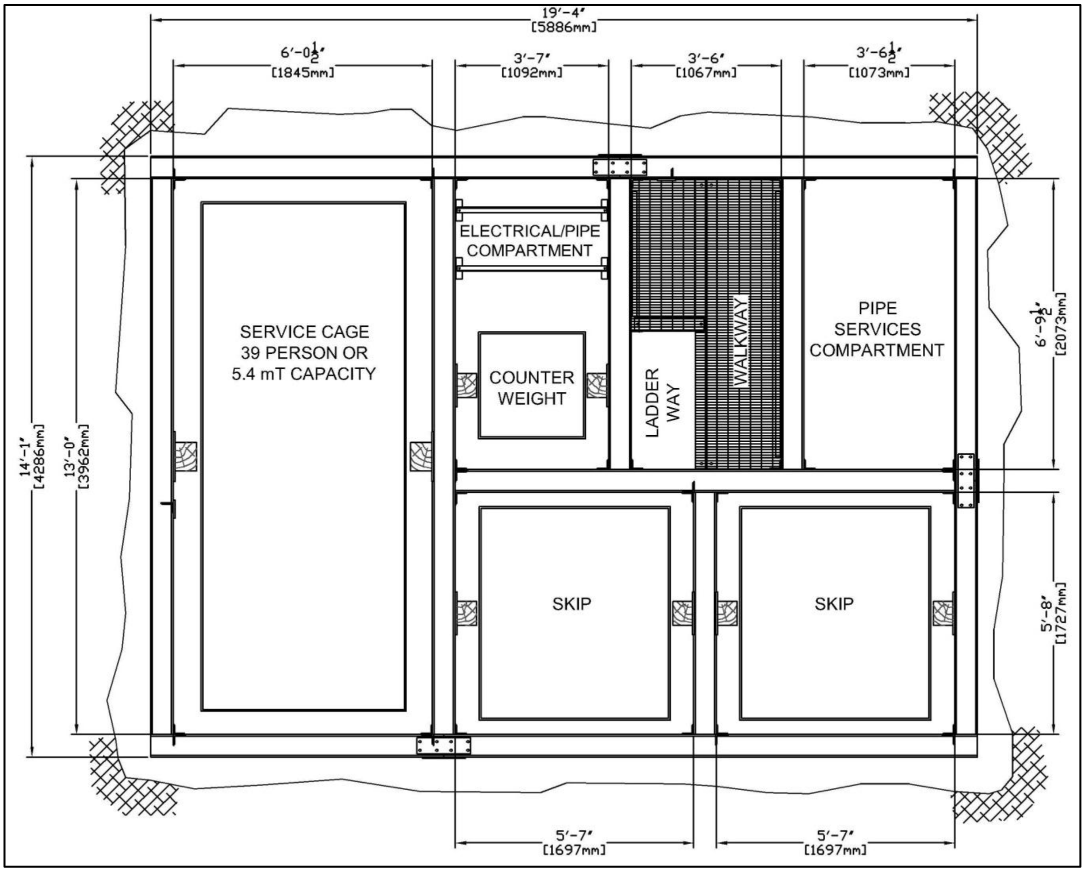

Figure 4-1: Ross Shaft: Typical Shaft Set (SRK, Courtesy Sanford Laboratory)

The Ross Shaft was in operation until the Homestake Gold Mine closed in 2003. Deterioration through corrosion and wear on the shaft steel, including studdles (vertical steel members placed between steel sets), sets, and bearing beams, prompted a full "strip and re-equip" project being performed by the Sanford Lab. The Ross Shaft layout will not be significantly modified from the existing configuration. The set spacing is being increased from 6 ft to 18 ft, but the general configuration is remaining the same to allow for emergency egress during rehabilitation. The shaft was installed with limited ground support, electing to utilize lacing to prevent spalled rock from reaching the personnel conveyances. The new design replaces this system with a pattern bolting system to control rock movement. The requirements for this shaft are safety, performance, and code driven and defined by the existing configuration. Most of the shaft rehabilitation and headframe work is planned to be executed by Sanford Laboratory with non-LBNF Project funds prior to LBNF construction beginning. The rehabilitation is just over 50% complete as of this report and is planned to be completed in 2017. Some items specific to LBNF, such as the development of the skip loading pocket for waste rock handling, will be requested to be funded using CD-3a funds from the LBNF project.

The production and service hoists at the Ross Shaft are located on the surface in a dedicated hoistroom west of the shaft. The service hoist operates the service cage and the production hoist operates the production skips. The DUSEL PDR describes the condition assessment of the electrical and mechanical hoisting systems which are described in detail in the Arup Preliminary Infrastructure Assessment Report (DUSEL PDR Appendix 5.M). These electrical and mechanical systems will have standard maintenance performed on them to make them in like new condition, but will not be modified from the existing design. The Ross Headframe steel requires some strengthening and modifications to meet code requirements. Responsibility and timing for this is still being discussed as of this report.

4.2.4 Yates Shaft

The Yates Shaft is rectangular in shape—15 ft-0 in (4.572 m) by 27 ft-8 in (8.433 m) measured to the outside of the set timbers. There are two cage compartments and two skip compartments as shown in **Figure 4-2**. In addition to the cage and skip compartments, there are two other compartments in which shaft services are located. The shaft collar is at 5,310.00 ft (1,618.49 m) elevation and the 4850L is the bottom level at elevation 376.46 ft (114.75 m) above sea level. Service is provided to 18 levels plus four skip-loading pockets. Sets are made up of various length and size timbers located to maintain compartment spaces. The Yates Shaft is timbered except for a fully concrete-lined portion from the collar to the 300L. Recent repairs include full set replacement from the concrete portion to the 800L and additional set repair below this level where deemed critical.

Finite Element Analysis (FEA) modeling by G.L. Tiley [12] showed that a dogging load produced by the cage would require vertical joint reinforcement, guide connection modifications, and additional new bearing beam installations. A dogging load occurs when emergency stop devices, called dogs, dig into the guides to stop the cage if the wire rope loses tension. This concern has been addressed by the Sanford Lab through installation of an independent structure within the existing headframe supporting two wire ropes that travel the depth of the shaft. Dogs can now dig into these ropes rather than the wood structure, transferring all load to the new structure. This system was only installed in one compartment, restricting general personnel travel to that compartment. Unmanned loads and shaft maintenance can be performed in the other compartment.

To reduce risk in the Yates Shaft, the Sanford Lab initiated a “top down” maintenance program in 2012. As the name implies, technicians began at the top of the shaft and are systematically removing wood lacing around the perimeter of the shaft, removing any rock behind the lacing, bolting the rock as necessary, then replacing the lacing. Any timber meeting a certain level of degradation is also replaced or reinforced during this process. The top down maintenance is approximately 50% complete as of this report, and should reach the 4850L in 2017. This process will substantially reduce risk associated with this shaft, but it is not intended as a long term solution. The shaft is planned to be fully stripped and re-equipped similar to the Ross shaft as soon as practical after construction of LBNF.

Similar to the Ross Shaft, there is both a production and service hoist at the Yates Shaft. The configuration of the hoists for the Yates Shaft is nearly identical to that of the Ross, with the only difference that the rope size for both hoists are the same at the Yates. The Yates Shaft hoists are located on the surface in a dedicated hoistroom east of the shaft.

The Yates Service Hoist and Production Hoist are planned to be used as existing, with maintenance performed to bring them into like new condition. Further details regarding the condition of the Yates Hoists’ electrical and mechanical condition can be found in Section 2.2 of the Arup *Preliminary Site Assessment Report* (DUSEL PDR Appendix 5.M).

Figure 4-2 shows the Yates Shaft timbered layout.

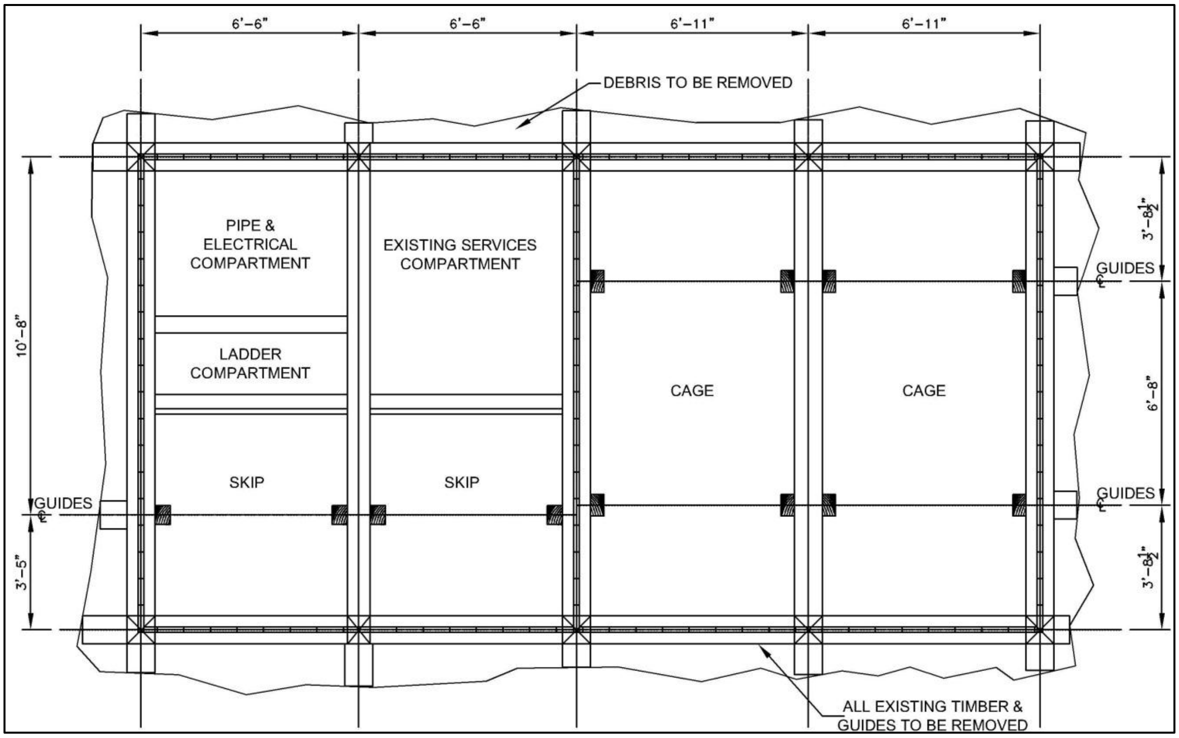

Figure 4-2: Existing Yates Shaft layout (Adapted from SRK, Courtesy Sanford Laboratory)

4.3 Ventilation

The ventilation system will utilize the existing mine ventilation system as much as possible with minimal modifications. Fresh air for the LBNF cavities and the utility drifts will be provided by pulling air directly from the existing drifts, which is supplied from the Yates and Ross Shafts. Air will be exhausted from the LBNF cavities and utility drifts through a spray chamber rejecting heat from the LBNF chilled water system into an existing exhaust route. 143,000-290,000 cfm design is required for heat extraction depending on intake temperature. 45,000-cfm passes through the each main experimental area (one air change per hour), with the balance of the air required for heat rejection coming directly from the shafts through existing drifts. A full ventilation modelling exercise will be completed later during preliminary design to understand the implications of these volumes. It may become necessary to split the exhaust and/or add booster fans at the 4850L to manage the volumes required. The environmental design criterion for LBNF underground spaces is shown in **Table 4-1**.

Table 4-1: Environmental Design Criteria (Arup)

Room	Internal Temperature	Humidity range	Min Ventilation rate/Fresh Air Changes	Occupancy (during assembly)	Additional Information
LBNF Cavities	40-82 ˚F (10-28 ˚C)	15-85%	1	20 (50)	See note 1 below
Access Drifts	Min 50˚F (10˚C)	Uncontrolled		Transient space	
Utility spaces / Electrical rooms	50-95 ˚F (10-35 ˚C)	Uncontrolled	1		
Storage Rooms	59-104 ˚F (15-40 ˚C)	Uncontrolled	Min 15 cfm/person	Room dependent	

* Occupancy of 20 during operations.

Note 1: Temperature, humidity and filtration requirements in localized areas of this space may differ, dependent on requirements. This will be provided by the experiment installation design team. The internal conditions stated above will be used to inform the design of plant and services for each space unless specific requirements that differ from this are provided by LBNF/Sanford Lab[oratory] or the lab experiment design teams.

The DUNE experimental spaces do not require air conditioning or humidification, but the cryogenic systems do. The drift temperatures are low enough that adequate cooling can be attained by a once through air only system (untreated air). Much of the experimental equipment will be directly water cooled by experiment-provided systems, and the heat rejected by that cooling system which will be integrated into the overall mine ventilation air flow scheme.

There are no cleanliness requirements for this project. General purpose (MERV 8) filters will be utilized to reduce any dust contamination entering the experiment and central utility cavern. An independent temporary clean room will be provided by the experiment during detector assembly, and is not included as part of LBNF.

Per historical data, outdoor temperatures can drop below -20°F; therefore, the intake air requires heating to prevent ice build-up in the shafts which could potentially disrupt hoisting operations and damage shaft support members, cables and piping. The existing shaft heaters are expected to be adequate for normal operation, but temporary supplemental heating may be necessary during excavation due to higher demands.

The HVAC systems will be controlled and monitored via Direct Digital Controls (DDC), through the Facility Management System (FMS).

4.4 Electrical

The underground facilities at the 4850L will have electrical power for normal operations as well as standby power for emergency occupant evacuation. LAr experiment power requires standby power for circulation of cryogens to avoid rapid boil-off and loss of argon.

4.4.1 Normal Power

The electrical systems both at the surface and underground are designed to meet International Building Code (IBC) and applicable portions of the National Electric Code (NEC) and National Electric Safety Code (NESC). Underground portions also comply with National Fire Protection Association (NFPA) Code 520, which is specifically intended for underground facilities.

The estimated electrical loads for both the LAr-FD experiment and the underground infrastructure serving the experimental spaces are included in the facility load determination and design. These loads are shown in

Power to serve the LAr-FD experiment will originate from the Ross substation and be routed down the Ross Shaft to the 4850L. One 15kV mining cable shall be installed down the Ross Shaft to the 4850L and shall be cable rated for mine use, highly flame retardant, low smoke toxicity with high tensile strength and self-supporting. At the 4850L, the 15-kV mining cable will terminate in 15-kV switchgear located in a new Ross underground substation. Facility power will be provided in a similar manner, with a dedicated power supply through the Ross shaft terminating in the new electrical substation near the Ross Shaft. This will be provided early in the construction process to allow it to be used for construction.

Varying voltages will be distributed at strategic locations at the 4850L for use by LBNF, DUNE, and the existing facilities. To conserve space within the drifts, armored cable with low smoke properties will be used to distribute normal power wiring throughout the 4850L.

The DUNE experiment equipment will have dedicated shielded transformers to serve each detector's electronics at 208Y/120V. In addition, LBNF mechanical equipment will be fed from a dedicated transformer. Above the detectors, electrical panels and small transformers will serve equipment operating in the detector cavity. High voltage equipment and cables will be located away from the detector to meet the experiment Electromagnetic Interference (EMI) requirements.

4.4.2 Standby and Emergency Power

A 300kW emergency/standby diesel generator will be provided in the Central Utility Cavern to serve standby and emergency loads. 48 hours of diesel fuel will be provided to operate the generator when surface power is inoperable. The following 4850L electrical loads are anticipated to be installed to the emergency/standby power system:

- Security
- IT System for communications
- Smoke control fans
- Mono rail
- Cryostat system controls

Separate automatic transfer switches and electrical distribution equipment will be provided for emergency and standby power. Automatic transfer switches will be installed at the 4850L in 2 hour rated electrical rooms. Upon loss of normal power transfer switches will operate to transfer the loads.

An existing independent generator provides standby power for the systems in the existing Refuge Chamber, and will not be modified for LBNF.

Emergency power will also be connected to the emergency/standby generator. Emergency power systems also will be provided via uninterruptible power supplies or integral storage batteries. A UL 924 listed centralize lighting inverter with 90 minute backup will be installed for emergency lighting. The central lighting inverter will serve as a backup to the main emergency generator system.

The following 4850L electrical loads are anticipated to be connected to the emergency power system:

- Emergency lights – in order to simplify the switching in the drifts and ramps, we have assumed all lights in the drifts and ramp to be on emergency power.
- Exit signs
- Fire alarm system

4.4.3 Fire Alarm and Detection

The 4850L will have notification devices installed to alarm the occupants of a fire. Notification devices will consist of speakers and strobe lights. Manual pull stations will be provided within 200 ft of egress. Phones will be installed in the liquid argon chambers and every 400 ft along the access drifts to communicate with the surface level command center.

An air sampling and gas detection system will be installed in the drifts and liquid argon detector chamber as an early detection of a fire condition. The air sampling system will be connected into the fire alarm system.

The fire alarm system will also interface with the Oxygen Depletion Hazard (ODH) system to activate the fire alarm system and initiate an alarm at the respective level fire alarm panel and at the surface level command center. Specific sounds and strobe colors will be identified based on the type of alarm (fire, ODH, etc.).

4.4.4 Lighting

Suspended lights mounted at a height just below the lowest obstruction will be provided for all drifts and ramps. Mounting is to be coordinated with conduit and supports of other systems running overhead. Maintained average illumination of approximately 24 lux (2.4 foot candles) at floor level will be provided throughout the drifts. Lighting control in drifts will be via low voltage occupancy sensors and power packs suitable for high humidity environments.

Lighting within equipment rooms will be UL Wet Location rated, watertight fluorescent fixtures. Exact layouts will be coordinated with final equipment at future design stages. Lighting control in equipment rooms will be via switch only, avoiding possibility of unexpected lights-off triggers.

All light fixtures within the liquid argon chamber will be UL Wet Location rated LED light fixtures to minimize Electromagnetic Interference (EMI) near the experiment. Average luminance levels at 0.7m above the liquid argon vessel roof will be between 100 and 150 lux (10-15 foot candles). All light fixtures will be controlled through a networked lighting control system allowing switching of multiple zones or circuits from multiple locations, and time schedule or other automated functions. Emergency light fixtures will be provided with 90 minute battery backup from a centralized system.

4.4.5 Grounding

The grounding system will be designed to provide effective grounding to enable protective devices to operate within a specified time during fault conditions, and to limit touch voltage under such conditions. The grounding system will be designed for a maximum resistance of 5 ohms where possible based on Mine Safety and Health Administration (MSHA) recommendations for ground resistance in mines. Ground beds, consisting of an array of ground rods, will be installed at each substation to provide low impedance to ground.

Main ground bars will be installed in the all substations. All extraneous conducting metal work will be bonded. A dedicated grounding cable will be distributed from the respective level substation ground bus to the LAr-FD detector chamber and from there to individual items of equipment and distribution boards.

A saturable inductor will be installed as part of the surface level work to mitigate common mode noise at the surface level transformers dedicated to the LBNF detector electronics. An Ufer grounding system will be provided by grounding the rebar within the liquid argon chambers to rock bolts which will be connected into the main 4850L grounding system. The Ufer grounding system will be connected to the main ground bus at the substation.

Electrical separation between the cryostat detectors and cavern utilities will be achieved by separating the metal components (rebar, structure support, etc.) from each other. Inductors will be installed between grounding systems to control noise between systems while also controlling touch potential for safety.

4.5 Plumbing

Plumbing provided by CF, but specific to DUNE, includes plumbing for the cooling systems and gas piping for nitorgen and argon delivery from the Cryogenic Compressor Building on surface to the Central Utility Cavern. Beyond this the facility requires supplies of both potable and industrial water, as well as a means to remove water inflows and sewage.

4.5.1 Industrial Water

An existing 4-inch industrial water riser will be used for construction and as a secondary fire service. It is not feasible to run an uninterrupted main water supply line from grade level down to serve the lower levels due to the extremely high hydrostatic pressure that would occur in the system. A series of pressure reducing stations are located at regular intervals in intermediate levels and at the 4850L in order to maintain the pressure within the capability of readily available piping.

4.5.2 Potable Water

Potable water is not required in large quantities for LBNF. The Sanford Lab experience has been that plumbing potable water through the shafts for low volumes is not effective, as the pressure reducing systems have the potential to introduce biological contaminants that result in the water no longer meeting drinking water standards, especially in low flow situations. To address this, local filters and ultraviolet treatment is done at the 4850L to make industrial water meet drinking water standards. This system has been used successfully for several years at the Sanford Lab.

4.5.3 Fire Suppression

The source of fire water main will be the existing 4-inch industrial water main at Ross Shaft. The connection to this line will be at the 4100L, where a new sump with at least 90,000 gallons capacity will be built using sump walls in an existing drift to provide 90 minutes of capacity even if the supply were cut off. The fire protection system at the 4850L Campus will be a gravity fed system. There will be a connection to an existing 6" industrial water main in the west drift fed from Yates Shaft, where a similar, but slightly smaller at 50,000 gallons, sump has been built by the Sanford Lab. This provides redundant supply from surface.

There will be multiple sprinkler zones in order to help determine the approximate location of a fire event. Sprinkler control valves will be located in the drifts, and will tap off the fire main running in the drifts.

Fire hose stations will be located along the drifts, LBNF caverns, and ancillary spaces at a maximum distance of
200 ft apart. The standpipe system will be a wet pipe type with supply valve open and under water pressure at all times. There will be a double interlock pre-action system in the LBNF experiment caverns activated by the smoke detectors to prevent any accidental sprinkler discharge over the sensitive equipment. A demand of 1000 gallons per minutes has been estimated based on 750 gpm sprinkler flow and 250 gpm hose stream.

4.5.4 Drainage

Drainage from the drifts, mechanical electrical rooms (MER), and any areas where spillage is likely to occur will be collected locally in open sumps. Sumps will be located every 500 in any areas where drainage to the drifts is not practical. Sumps will be equipped with sump pumps in a staged configuration where each pump discharging to the adjacent sump until water is discharged to the #6 Winze, where it flows to the primary facility pool approximately 1,000 feet below the 4850L. From there, the existing Sanford Lab dewatering system pumps the water in stages to the surface where it is treated before discharge into a nearby stream.

4.5.5 Sanitary Drainage

No sanitary drainage is included in the requirements for LBNF. Existing Sanford Laboratory facilities are planned to be used.

4.5.6 Chilled Water

The DUNE equipment will produce a significant amount of heat which will be removed by LBNF-provided chillers. Three chillers at 50% each have been selected to provide N+1 redundancy to allow for maintenance. Heat from the chillers and various process loads will be rejected using a spray chamber located at the east end of the 4850L LBNF caverns immediately before exhausting into the existing exhaust route. This location maximizes the available air flow by capturing air from both LBNF, the Davis Campus, and directly from either the Yates or Ross Shaft (or both). The ventilation air is a mixture of air (170,000-3500,000 CFM) from the Yates and Ross Shafts at approximately 68°F. This volume of air is such that the total heat rejected (2.5 MW or 740 Ton) will raise the air temperature to no more than

95°F. The dry coolers exhaust ductwork is arranged in a header and is ducted to the ventilation borehole.

Constant volume condenser water pumps are provided to also attain N+1 redundancy. The pumps shall be piped in a header arrangement to ensure maximum flexibility and redundancy in system. Each chiller shall have isolation valves to enable rotation. The FMS shall fully integrate with the chillers to enable/disable the condenser water system as necessary. A pressure transmitter shall monitor system pressure and shall annunciate a critical alarm to the FMS in the event of a low or high alarm. A chemical pot feeder is provided to ensure adequate water treatment in system.

A dedicated refrigerant relief vent line shall be provided from chillers to the drift downstream of exhaust fans near the exhaust ventilation borehole. In addition to this, the FMS shall monitor air quality in Chiller Room through the Refrigerant Leak Detection system. In the event of refrigerant leak detection, the chiller room exhaust motorized damper shall open (see damper matrix on design drawing) with a critical alarm annunciated to the FMS workstation. The chillers and its associated plant shall shutdown while the exit strobe lights and horns shall be activated. The system shall not restart until the refrigerant leak detector is re-set and the FMS operator has acknowledged and cleared the alarm event.

4.5.7 Nitrogen and Argon Gas Piping

Three 12” and three 8” mild steel pipes are provided by CF from the surface Cryogenic Compressor Building to the shaft, through the shaft, and across the 4850L to the Central Utility Cavern west entrance. The design and specifications of this piping are the responsibility of the Cryogenic Infrastructure Project team, as is the supply and isntallaiton within the Cryogenic Compressor Building and the Central Utility Cavern.

4.6 Cyberinfrastructure

The Structured Cable System design will be based on uniform cable distribution with a star topology. New fiber connections will be extended to the 4850 level from the Ross Dry Building, and will be dedicated to the use of LBNF experiments at the 4850 level. There is currently no requirement for redundancy in the connections to the experiments and the connection to the Ross Hoist presents a single point of failure. The design provides one (1) 96 –strand single mode armored fiber optic cable from the Control room dedicated to the experiments.Figure **4-3** shows the fiber distribution network for LBNF.

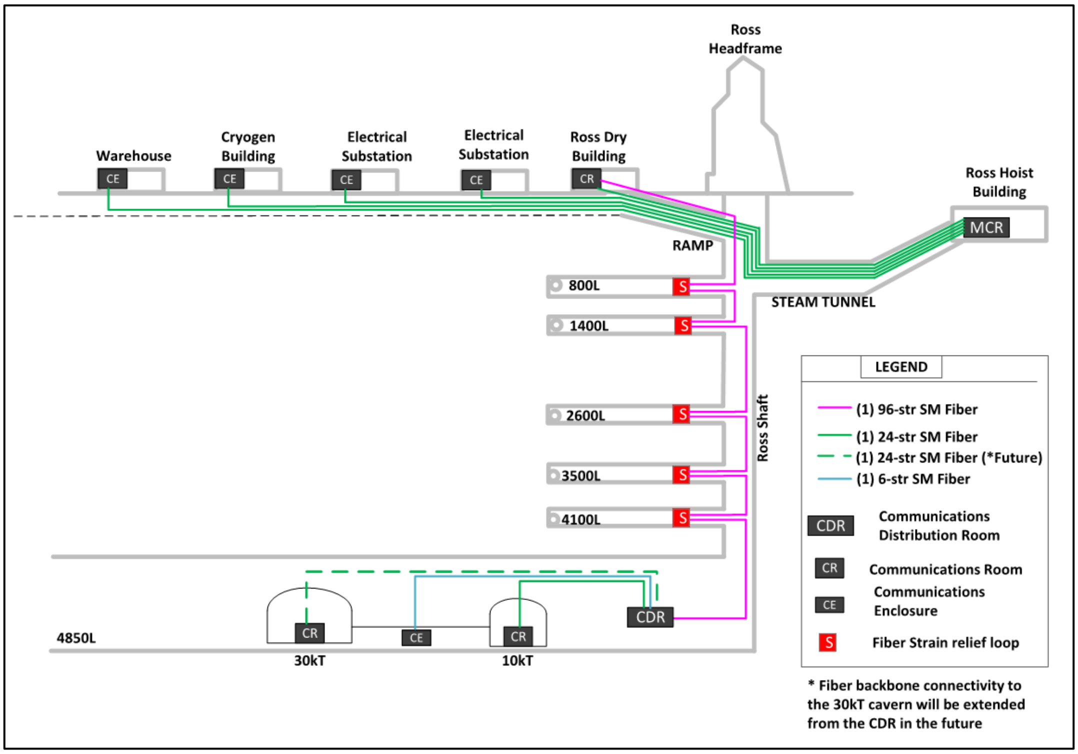

Figure 4-3: Fiber Distribution System for LBNF (Arup)

Voice communications are provided via two-way radios and phones distributed throughout the underground spaces (in every room as well as every 500 ft in drifts). Two-way radios utilize a leaky feeder system to ensure communications over long distance without line of site. These leaky feeders are cables that act as antennas installed the length of all drifts and shafts. Phones utilize Voice over Internet Protocol (VoIP) to provide communication though the fiber optic data backbone.

The data system is designed to provide 10-Gigabit Ethernet in the backbone and 1-Gigabit Ethernet to connected systems (computers). This system is intentionally left at a lesser level of design due to the continuous progression and advancement of technology that will almost certainly result in more advanced technologies than are currently available being utilized at the time of construction.

A Command and Control Center at the surface will be the primary location for Human Machine Interface (HMI) with the control system for both the LBNF mechanical and electrical systems and the experiment.

The fire alarm and control system will be an isolated system from the remainder of the cyberinfrastructure to ensure reliability of this system independent of the control system.

4.7 Waste Rock Handling

Prior to the commencement of any excavation activities, it will be necessary to establish a waste rock handling system. The capacity of this system will be equivalent to what was in place during mining. There are a number of components to the waste rock handling system, including refurbishing the Ross Shaft hoisting system, the Ross Shaft crushers, and a new conveying system to transport rock downhill to the Kirk Road.

The systems utilize experience and equipment from the former Homestake Mining Company legacy, where rock was removed to the surface using skips in both the Yates and Ross Shafts. At the headframe of each shaft, the material was crushed to a nominal ¾ in, passed through ore bins, and was transported via underground rail to the mill system. All systems from the underground to the crushers will be rehabilitated from the original systems.

During LBNF construction, the excavated waste rock material from the underground will be removed for disposal, with no intention of further processing. The Yates Shaft will primarily provide science access during construction. The Ross Shaft will be the means of removing of material from the underground during construction.

The Ross skipping system allows material to be transported at a rate of 3,300 tons per 18-hour day, allowing six hours of downtime for maintenance, breaks, shift changes, etc. The loading pocket at the 5000L for the 4850L will be cleaned of any accumulated sand during the skip pocket rehabilitation prior to excavation starting. Several components of the rock removal system require rehabilitation, including the loading system, the skips, the scroll and the bin at the top of the headframe, the crushers, the electrical service equipment, the belt conveyors, and the dust collector.

Once the excavated rock is crushed to 6” minus, it will be loaded onto a new series of conveyors for delivery to a bin adjacent to the Kirk Road approximately 500 vertical feet below the headframe. Here it will be loaded into trucks (assumed to carry 20 tons each) for transportation to the Gilt Edge Mine site, an abandoned gold mine planned to be undergoing remedial action per federal standards as a superfund site. The responsibility for final placement of the rock will be taken by the EPA as part of their remedial action. The route of the waste rock handling system is shown in Figure 4-4.

The design excavation volume with allowances for rock support and shotcrete will be approximately 330,000 cubic yards (yd^3) (250,000 cubic meters [m^3]). Assuming an average of 10.5 in (0.27 m) of combined overbreak and lookout, with a 50% swell factor, the total volume of waste rock is expected to be approximately 495,000 yd^3 (375,000 m^3). This equates to approximately 800,000 short tons of material. A detailed summary of each excavation space volume is included as part of Arup report [4].

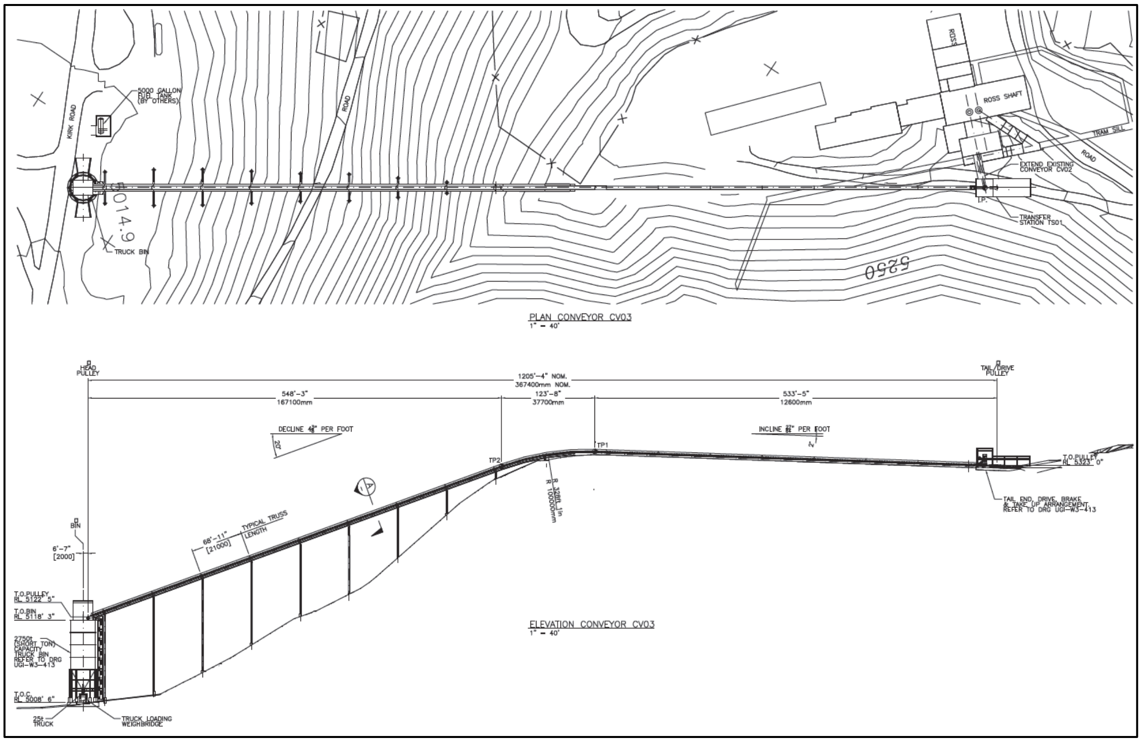

Figure 4-4: Waste Rock Handling System Route

5 SURF PREPARATION PROJECTS

5.1 Executive Summary

The Sanford Underground Research Facility (SURF) management team, comprised on both the SURF site office at Lawrence Berkeley National Lab (LBNL) and the operational management team at the South Dakota Science and Technology Authority (SDSTA), has identified a number of risks at the SURF site that require investment in 2015-2017 to mitigate risk and prepare for the construction of the Long Baseline Neutrino Facility (LBNF).

5.2 Background

The SDSTA was established by the State of South Dakota in 2008 to manage the site of the former Homestake Gold Mine in Lead, SD for use a dedicated science research facility. The state has since invested heavily into infrastructure repairs and upgrades to facilitate this conversion from a gold mine to a research facility. Several formal evaluations have taken place since the establishment of the SDSTA to understand risks and plan repairs accordingly. The most comprehensive evaluations were performed in 2009 by Arup, USA and their subcontractors for the underground aspects of the facility; and by HDR and their subcontractors for the surface aspects as part of the NSF sponsored Deep Underground Science and Engineering Laboratory (DUSEL) project. Additional evaluations have been performed by internal and external resources for more focused areas and/or newly identified risks. The most recent evaluation was performed in July 2014 by a review committee commissioned by the SURF site office at LBNL to review a number of specifically identified projects at that time. The results of this evaluation are included as an attachment to this white paper.

The results of the evaluations described have been used to inform investment decisions primarily sponsored by either the State of South Dakota or funding from the private donor T. Denny Sanford. The projects described within this report have been included as part of the LBNF budget.

5.3 Current Risks and Proposed Actions

The SURF engineering department maintains a list of high value projects based on risk review as well as desired improvements to the facility. This list is reviewed as needed with the management team, typically once every 6 months. Based on these reviews, a list of top priorities is established for planning purposes. The following sections describe projects that the SURF management team has deemed critical to address prior to construction of LBNF.

5.3.1 Hoist Motors

Four hoists are used for underground access at SURF, two at the Ross Shaft and two at the Yates shaft. These hoists are the original equipment installed in the 1930’s for mining. At each shaft there is an ore hoist for operating the skips, or rock buckets, and a cage hoist for operating the personnel conveyance. Each hoist uses several motors for power to isolate the surges created in starting and stopping the hoists from the utility provider through the use of a flywheel and motor generator (MG) system. Each hoist also has two independent motors to drive the over-wind (OW) and under-wind (UW) drums, which are attached to counterbalanced loads in the shaft. One of these hoist motors, the Yates ore hoist over-wind motor, failed in 2014 due to degradation of the insulation in the motor windings. This failure damaged the windings, resulting in significantly higher costs (~2X) than what would have been experienced if the insulation had been replaced prior to failure. To avoid repeating this failure, planned rebuilds have been scheduled for the remaining motors. These rebuilds have been prioritized based on both the tested condition and the importance to LBNF.

5.3.2 4850L Ground Support

The 4,850 foot level is host to the main physics experiments at SURF, and will become host for the LBNF project as well. A series of tunnels, or drifts, connect the Ross and Yates shafts at this level, forming a triangle inclusive of approximately 7,000 feet of running length. This level was flooded following mining, contributing to advanced corrosion of the ground support bolts and mesh used to bind the surface rock together and prevent pieces of rock from coming loose and falling, known in the mining industry as a "fall of ground". The level is routinely inspected by experienced miners to evaluate and address potential problems, but is also frequently travelled by scientists with no previous knowledge or training in how to identify risks. A fall of ground in this area would at best restrict access. At worst, it could be fatal if a person were passing through at the time of failure. To mitigate this risk, SURF has initiated a process to install permanent ground support system of resin bonded bolts with galvanized steel mesh to both secure large wedges of rock and prevent rocks larger than the mesh size from entering the occupied space. Some of this has been performed using state funding to date, so the budget included for LBNF is only to fund the balance of the work.

Despite the LBNF project efforts primarily utilizing the Ross shaft and newly secured drifts at the 4850L, it could be impacted from a fall of ground in this area. Scientists working at the Ross Campus are expected to travel through the Yates shaft and across the level to free the Ross shaft for LBNF use only. If access across the level were restricted, this may impact shaft logistics. More importantly, The Yates shaft is capable of managing loads longer than the Ross shaft, a benefit sure to be exploited. If the larger drift between shafts is restricted for some reason, load planning would need to change, including possibly reducing the size of major components.

5.3.3 Surface Adits and Tunnels

The majority of underground tunnels at SURF are only accessible through the shafts, but there are some tunnels that open to the surface at shallow depths. These include the very near surface tunnels connecting surface buildings with the shaft accesses, the tramway level used for ore management during mining, and the 300 foot level (300L) at the base of the adjacent Kirk Canyon. These surface exposures allow exposure to weather elements not experienced in tunnels fully underground, including the freeze/thaw cycle. The standard method of securing these tunnels during mining was to use large wooden timber supports to build wooden tunnels within the rock tunnel, leaving the rock unsupported unless poor rock conditions warranted additional support.

At the 300L, a timber failure was experienced at one of the two surface entrances (portals) to the 300L, prompting immediate action. The timber failure allowed a large weight to rest upon a power cable, though the cable was not damaged. To prevent further failures, new portals are recommended at one portal on the 300L, three portals on the tramway level (~175 feet below surface), and at the "Yates Tunnel" leading from the machine shop to the Yates shaft access. These three areas are required to support utilities. At the 300L, these consist of power, water, and communications cables. The tramway houses power, communications, water, and city sewer. The Yates Tunnel has the primary fiber optic connection for the facility. Between the Yates tunnel and the surface (less than 30') are a number of water and gas pipes that could be impacted by a failure of this tunnel.

The tramway has additional risks beyond the portals. A section of the underground portion has indications of degradation and potential failure of both the timber supports and the rock itself. Two surface buildings are exposed along the ~3,500 foot length of this level between the Ross shaft and the location where the mills had been located during mining. One of these had some maintenance performed in 2014 to prevent further degradation. The other is a wood framed structure that has several rafters cracked and/or broken. It is proposed to remove the majority of this unused structure, repairing the ends to prevent unauthorized entry into the underground.

5.3.4 Administrative Building Parking

A portion of the road adjacent to the administrative building parking lot and leading to the Yates headframe experienced ground movement while the facility was a gold mine. As a stop gap repair, the mine dug out the slumping area and placed a number of large limestone blocks in this area. A wet spring in 2014 showed evidence of movement of these blocks, with large cracks opening up parallel to the edge of the road. To avoid further damage, the area "downhill" of the cracks has been blocked from traffic and sandbags have been placed to direct water away from the cracks. A permanent repair for this area has been designed using SURF funding, with LBNF including the repair cost in the budget.

5.3.5 Water Inflow Controls

The open cut near SURF acts as a large funnel to the underground, catching rain water and snow melt and directing it through a number of opening to the underground. Controls in the form of walls and sumps are in place to direct this water away from the shafts and occupied areas, but during major storms the volume of water can exceed the capacity of these existing controls. A project was initiated by the SDSTA to catch this storm water as high as practical and provide a route adequate to support 100-500 year rainfall events. A one meter diameter borehole has been drilled and pipe has been purchased to take water from the base of this borehole and direct it to the #5 shaft, well outside of all occupied areas. Additional funding is required to complete this project. Until completed, access may be restricted during major storm events to protect people travelling through the shafts. There are existing controls to protect the facility and science infrastructure, but not the shafts. If a major storm event occurs during LBNF construction, the project may be responsible for paying "standing army" costs for several days until water levels recede unless this project is completed.

5.3.6 Oro Hondo Fan/Drive

Primary ventilation for the underground is provided through two shafts, the Oro Hondo Shaft and the #5 shaft, both of which have redundant fans at surface. However, the only fan capable of supporting the air volumes required to support major excavation such as LBNE is the American Davison fan at the Oro Hondo shaft. This fan uses a 3,000 Hp motor and is capable of volumes in excess of 500,000 cfm. The variable frequency drive supplying power to this fan is obsolete and parts are no longer available. The facility has experienced several failures of this drive since opening, which to date have been possible to repair due to used parts. A failure that cannot be repaired due to lack of parts will become more likely over time.

While this fan is the only fan capable of supporting excavation, it is also larger than necessary for excavation. Using a fan of this size at a lower speed has a significant impact on its' efficiency. It would be preferable to replace the fan with one more properly sized for LBNE excavation and ongoing operation to maximize efficiency. The estimated cost for a full fan replacement has been included in the LBNF budget.

5.3.7 Roof Structural Deficiencies

Preliminary evaluations of a number of roofs at SURF identified the potential of structural deficiency based on snow loads. Based on these preliminary results, a detailed analysis was performed on the Ross and Yates hoist and crusher buildings. This analysis confirmed the deficiencies based on current code.

Both hoist buildings were repaired in 2012 and 2013, but the crusher buildings are still at risk. Both crusher buildings are used daily for staging of materials at the shafts. The deficiency noted is in the rivets used to hold the trusses together. A failure of these rivets would be sudden and catastrophic, with no early indicators. The only means of evaluating these for cracks would be ultrasonic testing of every rivet, which is not practical. The Ross Crusher building will be used for its original purpose during LBNF excavation, while the Yates crusher building will be used for storage. The repairs for both buildings are included in the LBNF budget.

5.3.8 Refuge Chambers

The Mine Safety and Health Administration (MSHA) requires the use of refuge chambers for any underground area with only one means of egress to the surface. A refuge chamber is an air tight area with food, water, sanitary facilities, and breathable air supply for up to 96 hours based on the number of occupants defined by the facility. While SURF is not governed by MSHA, the South Dakota Office of Risk Management references MSHA standards as the most appropriate in many situations. Refuge chambers have been installed at the 1250L and 2450L pump rooms, accessible only through the Ross shaft. Two additional pump rooms at the 3650L and 5000L should have refuge chambers to meet this requirement and ensure workers have a safe area to await rescue if the Ross Shaft were to be unavailable for some reason. Budget is included in LBNF for both chambers.

5.3.9 Ross Shaft Operational Readiness

The Ross shaft has been undergoing a full rehabilitation process since 2013, removing all original steel, adding rock bolts and mesh for ground control, and installing new steel for the entire length. This project is anticipated to complete during calendar year 2017, which is the critical path for LBNE construction to begin. All access for construction will be through this shaft, and all excavated materials will be removed through this shaft. While the rehabilitation of this shaft has been funded through FY15 by State and private funds, funding beyond that and for several additional scope items has not been secured. The cage, or personnel conveyance, for this shaft was removed from service at the beginning of rehabilitation and replaced with a work deck specifically designed to support rehabilitation. A new cage will be required to support underground access for both LBNE and SURF upon completion. Similarly, the skips, or rock buckets, used for removing excavated material from the underground have been removed and replaced with a work deck on one side, and modified to support rehabilitation on the other. Two new skips should support the duration of LBNE excavation with proper maintenance.

The Ross Headframe structure was designed and built in the 1930’s. In that era, the headframe requirements did not include the ability to withstand a “rope break” load. This is the load that would be applied if one of the conveyances did not stop and was pulled against the sheave deck at the top. In this situation, the hoist is powerful enough to pull the headframe over. Modern code requires head frames to include this load in their design. Multiple limiting controls have avoided experiencing a rope break load in either headframe over the past 80+ years of operation, so the likelihood of this failure has been proven low, but if it were experienced, the facility would be shut down. Cost for both design and construction of headframe reinforcement at both the Ross and Yates Shafts has been included in the LBNF budget.

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